STORM RUNOFF AND BASEFLOW WATER QUALITY MODELING STUDIES FOR AUSTIN CREEKS

Prepared by

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TABLE OF CONTENTS

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EXECUTIVE SUMMARY

This study updates and summarizes the following City of Austin reports:

1. Stormwater Quality Modeling Study for Austin Creeks[1]
2. Barton Springs Water Quality Trend Analysis[2]
3. Baseflow Water Quality Trend Analysis for Austin Creeks[3]

The objectives of this study are to determine the existing water quality conditions and trends of Austin area creeks, and the effects of urban development on water quality of the creeks. The creeks included in this study are Barton, Bull, Shoal, Boggy, Williamson, Waller, Walnut, Bear, Onion, and Slaughter. The results of the study can be applied to all creeks in the Austin area based on the degree of watershed imperviousness for each creek. The water quality parameters included in this study are solids, organics, nutrients, bacteria, metals, and a few toxic substances. Data (1975-1987) were obtained mainly from the USGS/City of Austin cooperative monitoring program.

The study used statistical methods such as univariate analysis, regression, and analysis of variance. The SAS software was used for the statistical analysis. The analysis consists of rainfall modeling, rainfall to storm runoff to pollutant load/concentration regressions, and baseflow concentration level and time trend studies. The development condition of a watershed is represented by watershed imperviousness. The runoff volumes, pollutant loads, and concentrations for individual storms and for average annual condition were correlated with watershed imperviousness.

It was found that in general , both the storm runoff volume and pollutant load increase with increasing percent impervious cover. For several pollutant parameters, the storm event and baseflow mean concentrations also increased with imperviousness. There was either no significant time trend in storm event mean concentrations (EMC) or the EMC data are insufficient for time trend analysis. For most of the creeks and Barton Springs, the time trends of baseflow concentrations are not significant. However, there were significant time trends for some nutrient parameters at a few monitoring stations on Walnut, Williamson, and Onion Creeks.

In summary, the water quality of Austin area creeks depends to a large extent on the quality and quantity of stormwater runoff, which in turn depend on percent impervious cover. As percent impervious cover increases, stormwater runoff, pollutant load, and possibly pollutant concentration, increased for any given rainfall. Therefore, the fully urbanized high impervious cover watersheds such as Shoal and Boggy Creeks represent the worst water quality condition. The least developed watershed such as Barton Creek has the best water quality condition. The effect accelerates as the rainfall depth of the storm event increases.

INTRODUCTION

The study was conducted as part of the City of Austin (COA) water quality modeling program, and is an update of the previous COA reports.[1-3] The purpose of the study is to assess the current conditions and time and spatial trends of the in-stream water quality for Austin area creeks. The creeks included in this study are Barton, Bull, Shoal, Boggy, Williamson, Waller, Bear, Onion and Slaughter. The rainfall, daily streamflow, baseflow water quality, and storm runoff water quantity data were analyzed for all creeks. The storm runoff quality data were analyzed for all creeks except Waller, Walnut, Bear, Slaughter, and Onion Creeks for which data are insufficient for analysis. The results of the studies were generalized to apply to all Austin area creeks by correlating water quality and quantity data to watershed imperviousness.

Data were obtained mainly from the United States Geological Survey/City of Austin cooperative monitoring program (USGS/COA program). Since October 1974, the USGS has successively established a network of streamflow and rainfall gauges in the Austin area for storm runoff analysis. Automatic water quality samplers were installed at Bull, Barton, Shoal, Boggy, and Williamson Creeks to monitor storm runoff quality. Ninety-one storm events were monitored at these sites with between 14 to 21 storms for each site. For many creek sites, the grab samples were collected periodically to monitor baseflow and storm runoff water quality. At each site between 20 to 70 concentration values for a specific pollutant were obtained. The pollutant parameters for the storm runoff and baseflow water quality studies are listed in Table 1.

SCOPE AND OBJECTIVES

The Austin area creeks are tributaries of the Colorado River. The Colorado River in Austin consists of Lake Austin, Town Lake, and a section of the River below Town Lake Dam. The Colorado River, its tributaries, and the corresponding watersheds of the tributaries are shown in Figure 1. The hydrologic and water quality data of 14 monitoring sites on 10 creeks were analyzed. The study areas and monitoring sites are listed in Table 2. The development conditions of the study areas are listed in Table 3. The results of the analysis were generalized so that the water quality conditions of other Austin creeks can be estimated.

Since there are generally no significant point source pollution discharged into the Austin area creeks, the storm runoff pollutant load has been considered as the principal contributing factor impacting the water quality of Austin area creeks and thus the lakes. This study was performed to assess the extent of those water quality impacts, their causes and how water quality has changed over the period of record.

The objectives of this study are:

1. Document the in-stream water quality conditions of Austin creeks for both storm-event and baseflow conditions.

2. Quantify the effect of urban development on water quality of Austin

creeks.

3. Estimate the time trends of water quality conditions for Austin creeks.

DEFINITION OF TERMS

The following terms are often mentioned in this report. The definitions of the terms are given below.

Storm Runoff: The stormwater or rainfall runoff water resulting from a rainfall storm event. This water constitutes most of the streamflow in Austin creeks.

Baseflow: That portion of streamflow existing under non-storm event condition. The non-storm event condition is considered to exist when less than 0.05 inch rainfall occurs on the day of data collection, or when less than 0.5 inch or 1 inch rainfall occurs one or two days, respectively, before the data collection.

Percent Imperviousness: The ratio of the impervious area in the watershed to the total watershed drainage area multiplied by 100 percent. The impervious area is that portion of the drainage area which is covered by the impervious material. This calculation includes all the impervious area directly and indirectly connected to the storm sewer.

Significant: The status of a statistical test. It is said that the test of hypothesis is highly significant (H.S.), significant (S), or not significant (N.S.) depending on the probability levels of committing a type 1 error, i.e., rejecting a null hypothesis when it is true. In this report the probability levels of significance for F or Student's -t test are $p<0.01$, $P\leq0.05$ and $P>0.05$, respectively.

PREVIOUS STUDIES

In 1976, Espey, Huston and Associates[4] conducted a study for the City of Austin to evaluate the effect of land development on the quantity and quality of stormwater runoff into Lake Austin. The study used empirical equations to determine stormwater runoff quantity and quality for a specified storm under different development plans. The study concluded that the rate and volume of surface runoff, the pollutant concentrations, and total loading in surface runoff and in Lake Austin will be increased by urban development unless control measures are implemented. The empirical equations were based on very limited data, since there was practically no runoff and water quality data available for the Lake Austin watershed in 1976. In June 1978, Espey, Huston and Associates[5] presented the results of a stormwater runoff sampling program for the Austin Intensive Planning Area. The program included monitoring of two storm events in November 1977 for six stormwater sampling sites representing various land uses along the Colorado River in the Town Lake watershed., They estimated the stormwater runoff pollutant loadings that would result from a storm event for most of the Austin area watersheds and for four different land uses. The estimation, however, could not be generalized because of limited data.

The monitoring of in-stream stormwater and baseflow water quality conditions for Austin creeks was conducted by the City of Austin in recent years. The stormwater modeling study[1] developed storm rainfall to runoff to runoff pollutant load regression equations for various pollutant parameters in Barton, Shoal, Boggy, and Barton Creeks using the USGS/COA program data of 1975 to 1982. The study concluded that the storm runoff and pollutant load increased with increasing percent imperviousness. The baseflow and event mean concentrations increased with percent imperviousness for several pollutant parameters. Although the regression models were statistically calibrated, the precisions of the predictions using the models are low in a few cases. The regression equations were to be improved pending additional storm event data. Baseflow water quality trend studies for Barton Springs and Austin area creeks were conducted in 1985 and 1986, respectively. These studies indicate that except for a few cases there were no significant water quality degradation time trends for Barton Springs and various Austin creeks.

Using the 1975-87 USGS/COA program[6] data and the 1984-87 COA Stormwater Monitoring Program[7] data, the COA presented a study[8] describing the stormwater pollutant loading characteristics. The study correlated annual storm loading rates with percent imperviousness and population density for small single-land-use suburban areas and large multiple-land-use creek watersheds. The study reasonably assumed that the EMC's were independent of rainfall and runoff variables for each test watershed and calculated storm load as the product of mean EMC and storm runoff volume. Some of the results are closely related to the current study. These results are presented in this report.

UNIVARIATE AND REGRESSION MODELS

Most of the data, including storm rainfall and runoff variables, storm pollutant loads, pollutant event mean concentrations (EMC's), and baseflow pollutant concentrations, generally follow log-normal probability distributions. In some cases, these data values could be fitted to normal or both normal and log- normal distributions. The goodness of a fit was tested using normal probability plot and Shapiro-Wilk (for n<50) or Kolmogarov (for n>50) statistic as specified in the SAS User's Manual[9] and the EPA's Nonpoint Source Evaluation Guide.[10]

Variables such as storm duration, time between storms, and EMC's of specific test site were not dependent on other rainfall or runoff variables as described in previous COA studies.[1,8] The data of each of these variables or their log-transformations were fitted to a one-variable probability distribution, i.e., the univariate normal distribution. This distribution can be characterized by the mean, median, and variance of the data. The SAS UNIVARIATE program was used to test the normality of the distribution and to compute statistics such as mean, median, mode, variance, skewness, and coefficient of variance (Cv). The SAS ANOVA (analysis of variance) program was used to test if there is significant difference in data of each variable (i.e., means and variance) among various test sites.

If, however, a variable is dependent on other variables, the normal error linear regression model[11] should be applied to the relationship. The model requires that the dependent variable be normally distributed for any given values of the independent variables. In this connection, the regression model may be expressed in one of the following forms:

$$y = b_o \, X_1^{b_1} X_2^{b_2} \ldots X_n^{b_n} \qquad [1]$$

or

$$y = b_o + b_1X_1 + b_2X_2 + \ldots + b_nX_n \qquad [2]$$

Where Y is the dependent variable, X_i (i=1,2, ...,n) are independent variables, and b_i (i=0,1,..., n) are coefficients to be determined.

The data analyses of this report were performed using the above described univariate and regression models.

RAINFALL DATA ANALYSIS

The daily and storm-event rainfall data of the USGS/COA program between 1976 and 1987 and the storm-event rainfall data of the COA SWMP between 1984 and 1987 were analyzed. A comparison of the rainfall data among various sites indicates that there were not significant differences in the means and variances of the sequences of several rainfall variables including rainfall duration, rainfall intensity, number of dry days between rainfalls, storm rainfall depth, and monthly and annual rainfall depths. In other words, the rainfall characteristics are similar for various sites although the sequence and timing of the rainfall storms for these sites were different. The SAS ANOVA program was used for the comparisons. Consequently, the insufficiency of the rainfall data at one site can be satisfied using the data at other sites. For continuous simulation the rainfall data of one site were used to represent the rainfall conditions of all the sites. The daily rainfall data of Shoal Creek between 1976 and 1985 were chosen for this purpose.

Rainfall Duration

The duration data of all sites were divided into four seasonal groups. The log-transformed data of each group were fitted to the normal distribution. The median, arithmatic and geometric means, and coefficient of variation for each distribution are given in Table 4.

Rainfall Depth Versus Duration Relationships

For any given range of duration values, the corresponding data of rainfall depth were normally distributed. The arithmatic means of such normal distributions were computed. The values of arithmatic means of rainfall depth versus the corresponding average values of duration were fitted to linear regression equations as in [2], above. Table 5 presents the equations and their corresponding statistics for four seasonal groups. The regressions are highly significant. The levels of precision are generally good with $R^2>0.80$ and $Cv<0.50$. Using these equations, the expected or average rainfall depth for any given value of duration can be estimated.

Peak Rainfall Intensity Versus Average Rainfall Intensity Relationships

For any given range of average rainfall intensity values, the corresponding values of peak rainfall intensity were normally distributed. The values of arithmatic means of peak rainfall intensity versus the corresponding average values of mean rainfall intensity were fitted to linear regression equations as in [2], above. Table 6 presents the equations and their corresponding statistics for four seasonal groups. Using these equations the expected or average peak rainfall intensity for any given value of average rainfall intensity can be estimated. The average rainfall intensity equals the rainfall depth divided by the rainfall duration.

Analysis of Daily Rainfall Data

The Shoal Creek at 12th Street rainfall data were used to represent the rainfall conditions of all the creek watersheds. The Shoal Creek site was chosen because of its central location and the availability of its data. Table 7 presents the characteristics of the Shoal Creek daily rainfall data. The data were divided into six bimonthly groups. The mean daily rainfall depth and the number of dry days between rainfall days for each bimonthly group are presented in this table. A dry day is a day of no rainfall or rainfall depth being less than 0.05-inch. Generally no runoff will occur in a creek watershed resulting from 0.05 inch of rainfall.

For watershed simulation, the Shoal Creek daily rainfall data were arranged as a sequence of rainfall storms. A rainfall storm was defined as one day or a number of consecutive days of rainfall. The storms were separated by dry periods. One day was assumed to be the minimum dry period. A daily rainfall depth of less than 0.05 inch was assumed as no rainfall. The rainfall depth of a storm was the cumulative depth of all consecutive days of rainfall for an individual storm. The data of storm rainfall depth and number of dry days were fitted to log-normal distributions. The means and medians of the distributions are presented in Table 8.

STORM RAINFALL-RUNOFF RELATIONSHIPS

The storm runoff depth data for each creek can be generally related to rainfall depth data by geometric equations as expressed in [1], above. For lower impervious cover watersheds such as Barton, Bull, Bear, Slaughter, Onion, and Williamson, the storm runoff depth versus rainfall depth data were divided into wet and dry month data groups. The regression equations were developed for the two data groups. Table 9 presents the Storm runoff-rainfall relationships for nine creek sites.

Most of the runoff-rainfall relationships were developed in a previous COA study.[8] Using the Shoal Creek daily rainfall data of 1976-85 and the regression equations of Table 9, this study computed the average annual runoff coefficient for each of the creeks. These coefficients are presented in Table 10. In addition, the runoff coefficients were correlated with the watershed imperviousness as shown in Table 11 and Figure 2. The top curve of Figure 2 represents the correlation for streamflow condition. The mean runoff coefficient is the average value of yearly streamflow to rainfall ratios. The streamflow consists of storm runoff and baseflow. The bottom curve represents the correlation for storm runoff conditions. The mean runoff coefficient is the average value of yearly runoff to rainfall ratios. No baseflow is considered for this correlation.

STORM RUNOFF POLLUTANT LOAD

The runoff pollutant load for a storm can be estimated in two ways. The first method considers that the storm load is the product of runoff volume and mean event mean concentration (EMC). The runoff volume can be estimated from the runoff equations of Table 9 for a given amount of rainfall. The EMC can be estimated as either the arithmatic mean of a random variable or a function of rainfall and runoff variables. A previous COA study[8] indicated that the EMC's were in general not significantly related to rainfall and runoff variables. For a specific creek the EMC's were assumed to be randomly distributed. The median of the EMC's was used to represent the average water quality condition of the EMC's. The arithmatic mean was used for storm load computation.

The alternative method for storm load estimation is to consider storm load as a function of rainfall and runoff variables. It was found from the previous COA studies[1,8] that the storm load was significantly related to the volume of storm runoff but not to other variables. The storm loads were regressed on the runoff volumes. Some of the regression equations are shown in Table 12. A linear equation (L=aQ) in Table 12 indicates that the storm load is the product of runoff volume and a constant. This is equivalent to the estimate of the runoff volume multiplied by the mean EMC. In this connection, the slope or constant of the equation, a_1, is an unbiased estimate of the mean EMC. The geometric equations ($L=a_oQ^{a_1}$) in Table 12 indicate that the storm load to runoff volume ratio, i.e., the pollutant event mean concentration, changes with the storm runoff volume. This result deviates from that of the product of runoff volume and mean EMC. In finding the sum of the storm loads such as the annual load, however, the estimate computed from the linear equation (L=aQ) was approximately equal to that of the geometric function. Nomographs (Figure 3-7) of relating storm rainfall to runoff to load for several pollutant parameters were developed using the regression equations in Tables 9 and 12. A storm load can be estimated from the Nomographs for a given rainfall depth of the specific storm. The regressions of storm load on runoff volume were examined by F-tests and specific precision standards. The precision standards are necessary as a regression equation serves as a refinement of the load estimation. If the regression equation cannot fit to the data precisely, the regression simply biases the load estimation. In this case the first method(considering storm load being the product of runoff volume and mean EMC) should be used. The precision of estimate is considered adequate if $R_2>0.80$ and $Cv<0.50$. The regressions were all significant. The precision standards, however, could not be satisfied in many cases. These regressions which could not satisfy the precision standards are not listed in Table 12.

For simplicity and uniformity, the first method was used for storm load simulation. The storm load of a pollutant in the runoff equals the runoff volume multiplied by the mean EMC. The monthly and annual loads were obtained by summing the individual storm loads. The average annual storm load and in-stream storm load (storm load plus baseflow load) for each pollutant parameter and for each creek is given in Table 13-14. As a comparison, the storm loads were re-computed using the regression equations (alternative method) presented in Table 12. The annual storm and in-stream loads were also re-computed for the pollutant parameters and creeks of Table 12. The storm and annual loads obtained from both of the methods were compared using the SAS ANOVA program. There are no significant differences in the means and variances of these data between the two methods. The annual loads were further related with the percent watershed imperviousness. The relations are presented in Tables 15-16. For a watershed of given impervious cover, the annual loading rates can be predicted using these relationships.

LOAD PREDICTION WITHIN A STORM

As described in the previous section the storm load can be expressed as either a linear or a geometric function of the storm runoff volume. By the same token, the cumulative load (the sum of incremental load) at time ti within a storm can be a function of the cumulative runoff volume at time ti, i.e.,

$$L_{ti} = a_{oi} Q_{ti}^{a_{1i}} \qquad [3]$$

or

$$L_{ti} = a_i Q_{ti} \qquad [4]$$

where L_{ti} is the cumulative load at time ti(ti is measured from the beginning of a runoff event), Q_{ti} is the cumulative runoff volume at time ti, and a_{oi} a_{1i}, and a_i are coefficients to be determined.

For any runoff event with a runoff duration of T, given cumulative runoff volumes Q_{ti}, $ti<T$, the cumulative load L_{ti}, $ti \leq T$, can be estimated using equation [3] or [4]. The cumulative plot of load versus runoff volume can then be developed for the storm event.

Using Shoal Creek as an example, the cumulative TSS load at specific time within a storm is a function of the cumulative runoff at the particular time. Table 17 presents the TSS load versus runoff volume relationships at various times within a storm. For example, the relationship at the time of 20 percent of the total runoff being discharged is TSSL=495Q, where TSSL is the cumulative TSS load in pounds and Q is the cumulative runoff in inches. Similarly, the relationship at the time of the end of runoff, i.e., 100 percent runoff, is TSSL=440Q. The constants in the equations of Table 17 represent the instantaneous TSS concentrations within a storm. Therefore the TSS pollutograph (concentration versus time) for the storm event can be constructed. For the storm event of May 26, 1976, the cumulative plot of TSS load versus runoff was constructed using the equations of Table 17. Figure 8 shows the cumulative plots of the observed and simulated data.

The essence of the above paragraphs is to present a model for developing pollutographs. By the same token, a runoff hydrograph can be developed from rainfall data using the same procedure. It is expected that a separate study be prepared using this procedure in order to obtain more detailed information concerning storm runoff and runoff loading.

STORM EVENT MEAN CONCENTRATIONS (EMC'S)

As previously discussed, the in-stream EMC's for specific creek are not dependent on the rainfall and runoff variables. The original or log-transformed data of the EMC's are normally distributed. The distributions can be characterized by means, medians, and coefficients of variation of the EMC data. Tables 18-19 present these parameters for the creeks where the storm-event data are available.

The EMC's of Barton Creek are in general significantly lower than those of more urbanized creeks. The effect of urbanization on in-stream EMC's is significant for several parameters, including BOD, TP, NH3, TSS, and fecal coliform. Using watershed imperviousness as an index of urban development, the median TSS EMC for the low-imperviousness Bull Creek is substantially high. This is likely due to the effect of the construction activities, as the Bull Creek has been undergoing rapid urban development for the entire data period.

The storm event in-stream concentrations of some heavy metals and toxic parameters were studied. For each of these parameters there was generally one concentration value measured in a storm event. Therefore the data of instantaneous concentration instead of EMC's were analyzed using the SAS UNIVERIATE program. The medians and arithmatic means for these data are presented in Table 20. In most cases the effect of urbanization on the concentrations are obvious. A comparison of the data among creeks using the SAS ANOVA program indicates that the levels of As, diazinon, and malathion for the fully urbanized Shoal and Boggy creeks are significantly higher than those for the less urbanized Bull, Barton, and Williamson creeks. The toxic materials such as chlordane, DDD, DDE, DDT, and PCB were found in Shoal and Boggy Creeks, but not in Barton, Bull, and Williamson Creeks.

BASEFLOW WATER QUALITY

The baseflow concentration data were analyzed for 13 sites of 10 creeks. The concentration data were regressed on the discharge values of the baseflow. Except for a few parameters (e.g., TDS) the regressions were not significant. This suggests that the concentrations are not dependent on the quantity of baseflow. The seasonal variations of the concentration data are significant for some parameters. However, these data are generally insufficient to be subdivided for seasonally-grouped analysis. Therefore the concentration data of all individual observations were grouped as they were from the same population. The data were considered homogeneous as the storm-event concentration measurements were excluded and the number of observations from year to year is generally uniform.

The baseflow pollutant concentrations are best described by either normal or log-normal probability distributions. The baseflow water quality conditions can be characterized by the median, geometric mean, and coefficient of variation of the concentration data. The results of this analysis for 12 sites are given in Tables 21-33. A comparison of median concentrations among various creeks is shown in Table 34. It is clear that the water quality conditions of the less developed creeks are better than those of the fully developed creeks. The median concentration values were correlated with the percent imperviousness. The F-tests indicate that the correlations are significant for several parameters, including BOD, TP, NO_3, NO_2 + NO_3, TDS, fecal coliform and fecal streptococci. These correlations and the corresponding correlation coefficients are presented in Figures 9-13.

BASEFLOW WATER QUALITY TREND ANALYSIS

A trend analysis on baseflow water quality was conducted in 1986 using the USGS/COA program data of 1975-84. The study concluded that except for a few cases there is no significant water quality degradation trend in several Austin creeks. The data for other Austin creeks are insufficient for analysis. The current study generally confirms the previous finding using the USGS/COA program water quality data of 1975-87.

The baseflow concentration data for trend analysis are generally homogemeous, log-normally or normally distributed, and not dependent on baseflow quantity. The seasonal variation of the data were ignored due to the lack of sufficient data. Nevertheless, the time trend can be presented despite the appearance of the seasonal variations. A trend was detected by fitting the concentration versus time (year) data of 1975-87 to the normal error regression error model. The regression or time trend was examined for significance by F-test. The trend was significant for the following cases. Otherwise there was no significant water quality degradation trend for the creeks being studied.

For Walnut Creek at Webberville Road, the increases in TKN and NH_3 concentrations over years are significant. This is likely due to the rapid urbanization of the areas above the monitoring site. The increases in NO_3 and TN for Williamson Creek at Jimmy Clay Road are highly significant. There is a significant increase in TP concentration for the Onion Creek at Highway 183. Also, there are significant increases in TKN and TN for Onion Creek at Driftwood. These increases in pollutant concentrations for various creeks are probably due to urban or other development above the monitoring sites. Nevertheless, all the trends may be overstated in considering the insufficiencies of the precision and number of data points of the regression (R^2=0.40-0.68 and $N\leq13$). Three or more years of data are needed in order to better the trend analysis.

The results of the trend analysis are summarized in Table 35. The graphs of the significant trends are shown in Figures 14-20.

CONCLUSIONS

Storm runoff and baseflow water quality modeling studies were conducted to evaluate water quality conditions of the Austin creeks. The results of this study indicate that in the absence of structural stormwater control measures, the water quality of Austin creeks depends mainly on watershed development conditions. Specifically, the following conclusions can be drawn from the results of this study.

1. The in-stream pollutant loads produced from rainstorms can be estimated from the regression equation of storm load versus storm runoff volume. In most cases, the average value of these estimates for a pollutant is approximately equal to the product of the mean EMC's multiplied by the average runoff volume.

2. The in-stream pollutant loads increase with increasing storm runoff volume and EMC, which in turn, increase with increasing percent imperviousness. For several parameters, including TP, NH_3, BOD, TSS, fecal coliform, heavy metals, and some toxic substances, the in-stream storm event mean concentrations (EMC's) increase with percent imperviousness.

3. The baseflow water quality for Barton, Bull, Boggy, Shoal, Walnut, Bear, Slaughter, Williamson, and Onion Creeks, and Barton Springs were studied. Concentrations of TDS, BOD, NO_3, $NO_2 + NO_3$, TP, fecal coliform, and fecal streptococci show significant increase with increasing percent imperviousness.

4. A baseflow water quality time trend analysis indicates that there are few significant water quality degradation trends for the creeks listed in Item 3 above. There may be significant upward time trends in concentration for a few nutrient parameters in some sections of Walnut, Williamson, and Onion Creeks. More data are needed to determine if these trends really exist.

REFERENCES

1. City of Austin. Stormwater Quality Modeling for Austin Creeks. Watershed Management Division, January 1983. Revised November 1984.

2. City of Austin. Barton Springs Water Quality Trend Analysis. Watershed Management Division, October 1985.

3. City of Austin. Baseflow Water Quality Trend Analysis for Austin Creeks. Watershed Management Division, September 1986.

4. Espey, Huston and Associates. The Effect of Projected Urban Land Development on the Quantity and Quality of Stormwater Runoff into lake Austin. Prepared for Wallace, McHarg, Roberts and Todd, Urban and Ecological Planners, Philadelphia, Pennsylvania, and the City of Austin Planning Department, October 1976.

5. Espey, Huston and Associates.Study of Urban Stormwater Quality for Austin Intensive Planning Area. Prepared in cooperation with the Texas Department of Water Resources for Lower Colorado River Authority, June 1976.

6. U.S. Geological Survey. Hydrologic Data for Urban Studies in the Austin, Texas Metropolitan Area. Prepared in cooperation with the City of Austin, 1975-1986.

7. City of Austin. City of Austin Stormwater Monitoring Program Description. Department of Environmental Protection, 1986.

8. City of Austin. Stormwater Pollutant Loading Characteristics for Various Land Uses in the Austin Area. Department of Environmental Protection, July 1989.

9. SAS Institute, "SAS User's Guides: Basics and Statistics." Version 5 Edition, Gary, Norht Carolina, 1985.

10. U.S. Environmental Protection Agency, "Nonpoint Source Monitoring and Evaluation Guide." Draft Report, February 1988.

11. Neter, J.et al., "Applied Linear Regression Models," Richard D. Irwin, Inc., Homewood, Illinois, 1983.

TABLE 1

LIST OF WATER QUALITY CONSTITUENTS

Water Quality Constituents	Storm Runoff Water Quality	Baseflow Water Quality	Unit of Concentration
Total Suspended Solids	TSS	TSS	mg/l
5-Day Biochemical Oxygen Demand	BOD	BOD	mg/l
Total Organic Carbon	TOC	TOC	mg/l
Nitrate	NO_3	NO_3	mg/l
Nitrite & Nitrate	$NO_2 + NO_3$	$NO_2 + NO_3$	mg/l
Ammonia	NH_3	NH_3	mg/l
Total Kjeldahl Nitrogen	TKN	TKN	mg/l
Total Nitrogen	TN	TN	mg/l
Phosphorus	TP	TP	mg/l
Fecal Coliform	Fe. Col.	Fe. Col.	Col./100 ml
Fecal Streptococci	---	Fe. Stp.	Col./100 ml
Arsenic	As	---	mg/l
Copper	Cu	Cu	ug/l
Iron	Fe	Fe	ug/l
Lead	Pb	Pb	ug/l
Zinc	Zn	Zn	ug/l
Poly Chlorinated Biphenyl	PCB	---	mg/l
Chlordane	Chlord.	---	mg/l
DDD	DDD	---	mg/l
DDE	DDE	---	mg/l
DDT	DDT	---	mg/l
Diazinon	Diaz	---	mg/l
Malathion	Mala.	---	mg/l
Alkalinity	---	ALk.	mg/l
Turbidity	---	Turb.	NTU
Hardness	---	Hard.	mg/l
Total Dissolved Solids	---	TDS	mg/l
Dissolved Oxygen	---	DO	mg/l

Table 2

STUDY AREAS AND SAMPLING STATIONS

Creeks	Monitoring Sites	Period	Location	Drainage Area (sq.mi.)
Bull	*USGS 08154700	1978-87	@ Loop 360	22.3
Barton	*USGS 08155200	1978-87	@ Loop 360	116.0
Shoal	*USGS 08158050	1976-87	@ 12th Street	12.8
Boggy	*USGS 08156750	1976-86	@ Hwy. 183	13.1
Williamson	*USGS 08158920	1978-87	@ Oak Hill	6.3
Bear	USGS 08158810	1979-87	Near Driftwood	12.2
Onion	USGS 08158700	1979-87	Near Driftwood	124.0
Onion	USGS 08159000	1976-87	@ Hwy. 183	321.0
Slaughter	USGS 08158840	1978-87	@ FM 1826	8.2
Waller	USGS 08157000	1978-81	@ 38th Street	2.3
Walnut	USGS 08158600	1976-87	@ Webberville Rd.	51.3
Walnut	USGS 08158640	1976-86	@ So. Pac. Rail Rd. Bridge	53.5
Williamson	USGS 08158970	1976-87	@ Jimmy Clay Rd.	27.6

* Equipped with automatic water quality sampler.

TABLE 3

WATERSHED DEVELOPMENT CONDITIONS

Creeks/ Watersheds	Impervious Cover(%)	Development Condition
Bull @ Loop 360	12	Suburban/Developing
Barton @ Loop 360	7	Rural/Suburban/Developing
Shoal @ 12th Street	47	Urban/Fully Developed
Boggy @ Hwy. 183	41	Urban/Fully Developed
Williamson @ Oak Hill	15	Suburban/Developing
Bear Near Driftwood	9	Rural/Suburban/Developing
Onion Near Driftwood	3	Rural/Developing
Onion @ Hwy. 183	8	Rural/Suburban/Developing
Slaughter @ FM 1826	13	Suburban/Developing
Waller @ 38th Street	43	Urban/Fully Developed
Walnut @ Webberville Road	22	Urban/Suburban/Developing
Walnut @ So. Pac. Rd. Bridge	22	Below Walnut Creek W.T.P.
Williamson @ Jimmy Clay Road	24	Suburban/Developing

TABLE 4

CHARACTERISTICS OF RAINFALL DURATIONS
FOR AUSTIN WATERSHEDS
(LOG-NCRMAL DISTRIBUTIONS)

Data Group	Arithmatic Mean(Hrs.)	Geometric Mean(Hrs.)	Median (Hrs.)	Coefficient of Variation
Dec-Feb	5	4	5	0.83
Mar-May	4	3	3	0.73
Jun-Aug	3	2	2	0.98
Sep-Nov	5	4	4	0.67
Annual Values	4	3	4	0.82

* In estimating the duration of a storm the minimum dry time between storms was assumed to be 6 hours. Rainfall of less than 0.02-inch depth during a 6 hour period was assumed to be no rainfall.

TABLE 5

REGRESSION EQUATIONS OF RAINFALL DEPTH - DURATION RELATIONSHIPS FOR AUSTIN CREEK WATERSHEDS

($P = a_o + a_1 T$ where P is average rainfall depth, T is rainfall duration, a_o and a_1 are regression coefficients)*

Data Group	No. of Data pts.	Range of T (Hrs.)	Coeff. a_o	Coeff. a_1	R^2	F-test
Dec-Feb	11	1.25 - 60	0	0.15	0.85	H.S.
Mar-May	20	1.00 - 45	0	0.18	0.87	H.S.
Jun-Aug	16	1.00 - 50	0	0.20	0.83	H.S.
Sep-Nov	18	0.50 - 42	0	0.16	0.82	H.S.

* The units of P and T are in inches and hours, respectively.

TABLE 6

REGRESSION EQUATION OF PEAK RAINFALL INTENSITY-
AVERAGE RAINFALL INTENSITY FOR AUSTIN CREEK WATERSHEDS

($I_p = a_o + a_1 I_a$, where I_p is peak rainfall intensity, I_a is average rainfall intensity, and a_o and a_1 are regression coefficients)*

Data Group	No. of Data pts.	Range of I_a	Coeff. a_o	Coeff. a_1	R^2	F-test
Dec-Feb	10	0.03 - 4.50	0	2.37	0.91	H.S.
Mar-May	13	0.03 - 4.80	0	2.54	0.87	H.S.
Jun-Aug	13	0.03 - 4.20	0	2.77	0.93	H.S.
Sep-Nov	12	0.03 - 4.80	0	2.50	0.85	H.S.

* The unit of I_p and I_a is in inches per hour.

TABLE 7

SHOAL CREEK DAILY RAINFALL DATA

Data Group	No. Dry Days Between Rains Mean	No. Dry Days Between Rains Median	No. of Raining Days Mean	No. of Raining Days Median	Daily Rainfall Mean	Daily Rainfall Median
Jan-Feb	5	3	12	15	0.37*	0.21
Mar-Apr	5	3	12	15	0.55	0.33
May-Jun	3	1	20	30	0.74	0.38
Jul-Aug	7	3	9	15	0.49	0.29
Sep-Oct	4	2	15	20	0.67	0.43
Nov-Dec	4	3	15	15	0.47	0.20
Annual Values	5	3	83	110	0.57	0.34

* Daily rainfall depth in inches

TABLE 8

STORM TO STORM RAINFALL DATA USING SHOAL CREEK DAILY RAINFALL RECORD

Data Group	No. Dry Days Between Storms Mean	No. Dry Days Between Storms Median	No. of Storms Mean	No. of Storms Median	Storm Rainfall Mean	Storm Rainfall Median
Jan-Feb	8	5	7	4	0.61*	0.53
Mar-Apr	8	6	8	6	1.15	0.98
May-Jun	6	5	10	9	1.98	1.54
Jul-Aug	10	7	6	4	0.93	0.86
Sep-Oct	6	5	10	8	1.16	0.96
Nov-Dec	7	5	9	7	0.77	0.64
Annual Values	8	6	50	38	1.10	0.92

* Storm rainfall depth in inches

Table 9

REGRESSION EQUATIONS OF STORM RUNOFF-
RAINFALL RELATIONSHIP FOR AUSTIN CREEKS

($Q = a_o P^{a_1}$, where Q is storm runoff depth in inches, P is storm-rainfall in inches, and a_o and a_1 are regression coefficients.)

Creeks	Data Group	No. of Data pts.	Range of P (Inches)	Coeff. a_o	Coeff. a_1	R^2	F-test
Bull @ Loop 360	Dry	13	0.19-3.27	.0130	1.2305	.75	H.S.
	Wet	26	0.25-8.29	.0630	1.7481	.92	H.S.
Barton @ Loop 360	Dry	82	0.13-3.40	.0	.0	—	—
	Wet	24	0.29-7.03	.0432	2.2390	.87	H.S.
Williamson @ Oak Hill	Dry	16	0.29-5.62	.0196	1.9061	.71	H.S.
	Wet	24	0.18-16.75	.0734	1.9925	.91	H.S.
Shoal @ 12th St.	Combined	35	0.18-8.30	.1819	1.4075	.88	H.S.
Boggy @ Hwy. 183	Combined	45	0.09-5.81	.1732	1.5196	.83	H.S.
Waller @ 38th St.	Combined	50	0.08-5.75	.1959	1.6140	.93	H.S.
Walnut @ Webberville Rd.	Combined	36	0.06-9.77	.1045	1.6802	.87	H.S.
Bear near Driftwood	Dry	10	0.53-5.42	.01123	1.9283	.77	H.S.
	Wet	18	0.22-14.56	.0540	1.8880	.76	H.S.
Slaughter @ FM 1826	Dry	14	0.13-7.20	.0004	2.8171	.78	H.S.
	Wet	21	0.21-14.71	.02425	2.1212	.88	H.S.
Onion near Driftwood	Dry		0.13-4.03	.0002	2.5890	.83	H.S.
	Wet	15	0.31-7.02	.0101	2.7177	.85	H.S.

TABLE 10

AVERAGE ANNUAL RUNOFF COEFFICIENTS FOR AUSTIN CREEKS

Creeks	Percent Imp.	Storm Runoff to Rainfall Ratio	Streamflow to Rainfall Ratio
Bull & Loop 360	12	10	16
Barton & Loop 360	7	10	13
Shoal & 12th Street	47	22	24
Boggy & Hwy. 183	41	21	23
Williamson & Oak Hill	15	14	21
Bear Near Driftwood	9	9	15
Onion near Driftwood	3	6	12
Slaughter & FM 1826	13	10	17
Waller & 38th St.	43	28	33
Walnut & Webberville Rd.	22	15	18

TABLE 11

AVERAGE ANNUAL RUNOFF COEFFICIENTS
VERSUS PERCENT WATERSHED IMPERVIOUSNESS

	5%	10%	20%	30%	40%	50%
Storm runoff-Rainfall Ratio	0.07	0.10	0.14	0.18	0.22	0.30
Streamflow-Rainfall Ratio	0.15	0.17	0.19	0.22	0.25	0.30

TABLE 12

REGRESSION EQUATIONS OF STORM RUNOFF LOAD-RUNOFF VOLUME RELATIONSHIP
FOR SOME AUSTIN CREEKS

($L=a_oQ^{a_1}$ or $L = aQ$, where L is storm runoff load, Q is storm runoff volume, and a_o, a_1, and a are regression coefficients)

	SHOAL		BOGGY		WILLIAMSON		BULL		BARTON	
Pollutants	Equation*	R^2	Equation	R^2	Equation	R^2	Equation	R^2	Equation	R^2
TSS	L=442Q	0.94	L=479Q	0.91	L=162Q	0.80	---	---	$L=382Q^{1.426}$	0.86
BOD	$L=2.15Q^{.882}$	0.80	---	---	L=2.01Q	0.84	L=1.75Q	0.95	$L=1.632Q^{1.239}$	0.92
NO3	L=0.153Q	0.93	---	---	L=0.091Q	0.91	L=0.137Q	0.98	$L=0.034Q^{0.848}$	0.87
TKN	---	---	---	---	L=0.771Q	0.85	L=1.188Q	0.95	$L=0.526Q^{1.271}$	0.86
NH3	L=0.046Q	0.96	---	---	---	---	$L=0.037Q^{1.179}$	0.87	$L=0.037Q^{1.443}$	0.84
TP	L=0.307Q	0.93	---	---	---	---	L=0.164Q	0.96	$L=0.64^{1.194}$	0.84
TOC	---	---	---	---	L=8.82Q	0.87	L=11.4Q	0.92	---	---
Fe.Col.	---	---	---	---	L=117360Q	0.83	$L=55270Q^{1.146}$	0.84	$L=42190Q^{1.311}$	0.84

* The number of data points for each equation is 13-21. The coefficients of variation for all load estimates are less than 0.50. For units of variables, see Figures 3-7.

TABLE 13

AVERAGE ANNUAL STORM RUNOFF LOADING RATES FOR AUSTIN CREEKS*

Pollutants	Barton	Bull	Williamson	Boggy	Shoal
TSS	583	1225	1141	3133	3255
BOD	3.33	5.36	10.27	19.78	20.56
TOC	16	30	45	64	67
NO_3	0.18	0.32	0.48	0.69	0.72
$NO_2 + NO_3$	0.20	0.35	0.53	0.76	0.79
TKN	1.04	2.60	3.88	5.61	5.83
NH_3	0.07	0.07	0.09	0.23	0.24
TN	1.25	2.99	4.45	6.43	6.68
TP	0.14	0.28	0.63	1.97	2.05
Fe.Col.	1030	1949	4778	10822	14448

* The unit of fecal coliform loading rates is in million colonies per acre. The unit of other pollutant loading rates is in pounds per acre.

TABLE 14

AVERAGE ANNUAL STREAMFLOW LOADING RATES FOR AUSTIN CREEKS*

Pollutants	Barton	Bull	Williamson	Boggy	Shoal
TSS	583	1225	1142	3133	3256
BOD	3.40	5.64	10.57	19.82	20.60
TOC	16	32	46	64	67
NO_3	0.19	0.34	0.54	0.70	0.76
$NO_2 + NO_3$	0.21	0.38	0.59	0.77	0.83
TKN	1.08	2.75	4.05	5.62	5.85
NH_3	0.07	0.07	0.10	0.23	0.24
TN	1.55	3.20	4.71	6.46	6.74
TP	0.14	0.29	0.70	1.98	2.06
Fe.Col.	1037	1957	4782	10822	14478

* The unit of fecal coliform loading rates is in million colonies per acre. The unit of other pollutant loading rates is in pounds per acre.

TABLE 15

Average Annual Storm Loading Rates
Versus
Watershed Imperviousness For Large Creek Watershes

	Land Use and Watershed Imperviousness						
	Undeveloped	Low Density		Medium Density		High Density	
Pollutants	5%	10%	15%	20%	30%	40%	50%
TSS	466	740	1032	1330	2135	3128	4909
BOD	2.7	4.9	7.7	10.2	16.0	23.1	33.5
TOC	16.5	31.7	38.7	46.0	60.1	74.1	100.4
NO3	0.12	0.24	0.38	0.45	0.59	0.72	0.98
NO2+NO3	0.13	0.26	0.40	0.48	0.63	0.77	1.05
NH3	0.06	0.08	0.09	0.15	0.23	0.36	0.49
TKN	0.93	1.97	3.44	4.09	5.34	6.59	8.93
TN	1.04	2.18	3.78	4.50	5.87	7.24	9.82
TP	0.11	0.28	0.56	0.82	1.47	2.31	3.57
Fe. Col.*	622	1406	3316	5106	8173	12699	20247

* The unit of fecal coliform loading rates is million colonies per acre.
The unit of other pollutant loading rates is pounds per acre.

TABLE 16

Average Annual Stream Loading Rates
Versus
Watershed Imperviousness For Large Creek Watershes

	Land Use and Watershed Imperviousness						
	Undeveloped	Low Density		Medium Density		High Density	
Pollutants	5%	10%	15%	20%	30%	40%	50%
TSS	467	740	1032	1330	2135	3129	4910
BOD	2.84	4.96	7.77	10.27	16.05	23.09	33.53
TOC	17.13	31.87	38.90	46.24	60.25	74.27	100.70
NO3	0.1356	0.2447	0.3874	0.4617	0.6062	0.7453	1.0208
NO2+NO3	0.1485	0.2663	0.4142	0.4934	0.6472	0.7960	1.0906
NH3	0.0641	0.0784	0.0961	0.1555	0.2289	0.3640	0.4937
TKN	0.99	1.99	3.46	4.11	5.36	6.60	8.95
TN	1.13	2.21	3.81	4.53	5.91	7.28	9.89
TP	0.1134	0.2827	0.5615	0.8210	1.4704	2.3074	3.5739
Fe. Col.*	622	1406	3317	5106	8174	12701	20270

* The unit of fecal coliform loading rates is million colonies per acre.
The unit of other pollutant loading rates is pounds per acre.

TABLE 17

REGRESSION EQUATIONS OF CUMULATIVE TSS LOAD-CUMULATIVE RUNOFF WITHIN A STORM FOR SHOAL CREEK WATERSHED

(TSSL = aQ where TSSL is cumulative load in pounds per acre within a storm, Q is cumulative runoff in inches within a storm, and a is regression coefficient).

Time Within a Storm	Regression Equations	Coefficient of Variation	R^2	F-test
@ 20% of total runoff	TSSL = 495 Q	0.34	0.94	H.S.
@ 40% of total runoff	TSSL = 534 Q	0.32	0.95	H.S.
@ 60% of total runoff	TSSL = 540 Q	0.30	0.96	H.S.
@ 80% of total runoff	TSSL = 494 Q	0.32	0.96	H.S.
@ 100 % of total runoff	TSSL = 442 Q	0.37	0.94	H.S.

TABLE 18

MEDIANS AND GEOMETRIC MEANS OF EMC'S
FOR MULTIPLE-LAND-USE WATERSHEDS

Creeks	Barton		Bull		Williamson		Boggy		Shoal	
Imp. Cover	7		12		15		41		47	
Parameters	G.M.*	Median	G.M.	Median	G.M.	Median	G.M.	Median	G.M.	Median
TSS	700	730	1,600	1,970	1,000	900	1,900	2,100	1,900	2,100
BOD	4	4	7	5	9	9	12	11	12	11
TOC	19	22	39	40	39	40	39	40	39	40
$NO_2 + NO_3$	0.24	0.25	0.46	0.44	0.46	0.44	0.46	0.44	0.46	0.44
NH_3	0.08	0.08	0.08	0.08	0.08	0.08	0.14	0.14	0.14	0.14
TKN	1.3	1.3	3.4	3.5	3.4	3.5	3.4	3.5	3.4	3.5
TN	1.5	1.6	3.9	4.0	3.9	4.0	3.9	4.0	3.9	4.0
TP	0.19	0.18	0.41	0.36	0.63	.67	1.3	1.3	1.3	1.3
Fe. Col.	22	28	45	37	74	86	116	130	116	130

* The unit of fecal coliform is 1,000 colonies per 100 milliliter. The unit of other parameters is milligram per liter.

TABLE 19

ARITHMATIC MEANS AND COEFFICIENTS OF VARIAITONS OF EMC'S
FOR MULTIPLE-LAND-USE WATERSHEDS

Creeks	Barton		Bull		Williamson		Boggy		Shoal	
Imp. Cover	7		12		15		41		47	
Parameters	A.M.*	Cv	A.M.	Cv	A.M.	Cv	A.M.	Cv	A.M.	Cv
TSS	800	0.68	1,800	0.63	1,500	0.93	2,050	0.35	2,050	0.49
BOD	5	0.67	8	0.73	8	0.46	14	0.80	14	0.50
TOC	33	1.24	45	0.68	45	0.40	45	0.40	45	1.08
$NO_2 + NO_3$	0.25	0.98	0.47	0.23	0.47	0.33	0.47	0.58	0.47	0.62
NH_3	0.11	0.86	0.11	0.86	0.11	1.09	0.22	1.05	0.22	0.80
TKN	1.70	0.91	4.0	0.74	4.0	0.53	4.0	0.75	4.0	0.74
TN	1.90	0.95	4.4	0.48	4.4	0.43	4.4	0.58	4.4	0.68
TP	0.20	0.66	0.41	0.65	0.70	0.60	1.40	0.59	1.40	0.71
Fe. Col.	28	0.64	49	0.63	93	0.63	190	0.91	190	0.95

* A.M. and Cv are arithmetic mean and coefficient of variation, respectively. The unit of fecal coliform is 1,000 colonies per 100 milliliter. The unit of other parameters is milligram per liter. Arithmatic means were used in loading rate computations.

TABLE 20

STORM RUNOFF INSTANTANEOUS CONCENTRATIONS OF HEAVY METALS AND TOXIC SUBSTANCES FOR AUSTIN CREEKS

Creeks	Barton		Bull		Williamson		Walnut		Boggy		Shoal	
% Imp.	7		12		15		22		41		47	
Pollutants	A.M.	Median	A.M.	Median	A.M.	Median	A.M.	Median	A.M.	Median	A.M.	Median
As*	0.9	1.0	1.7	1.0	1.9	1.0	1.5	1.3	4.9	3.0	6.7	3.9
Cu	3.4	3.0	2.6	2.0	2.4	1.5	3.0	2.3	3.7	3.0	4.6	3.0
Pb	3.7	2.0	2.1	1.0	2.4	1.0	3.7	3.8	3.3	1.0	4.8	3.0
Zn	22.0	10.0	7.4	7.0	7.4	7.5	6.7	5.8	8.9	10.0	11.0	5.0
PCB	0	0	0	0	0	0	0	0	0.01	0	0.03	0.02
Chlord.	0	0	0	0	0	0	0	0	0.06	0	0.29	0.20
DDD	0	0	0	0	0	0	0	0	0.07	0.03	0.09	0.06
DDE	0	0	0	0	0	0	0.004	0.003	0.17	0.03	0.19	0.15
DDT	0	0	0	0	0	0	0.006	0.003	0.17	0.03	0.19	0.15
Diaz	0.08	0.01	0.07	0.04	0.08	0.07	0.08	0.07	0.15	0.15	0.29	0.24
Mala.	0	0	0	0	0.01	0	0	0	0.02	0.01	0.03	0.01

* As, Cu, P_b, and Zn are dissolved elements. See Table 1 for units.

TABLE 21

BASEFLOW WATER QUALITY FOR ONION CREEK NEAR DRIFTWOOD*

Parameters	No. of Data Pts.	Distribution	Median	G.M.	A.M.	Coeff. of Variation
TSS	45	Log-Normal	1	0.8	2	1.24
TDS	39	Normal	270	269	269	0.06
BOD	43	Log-Normal	0.5	0.4	0.57	0.79
TOC	45	Log-Normal	1.7	2.0	2.7	1.01
NO_3	33	Log-Normal	0.09	0.05	0.15	1.73
NO_2+NO_3	45	Log-Normal	0.10	0.06	0.16	1.67
TKN	44	Log-Normal	0.9	0.18	0.25	0.90
TN	44	Log-Normal	0.33	0.32	0.42	0.80
NH_3	45	Log-Normal	0.01	0.01	0.02	1.22
TP	45	Log-Normal	0.01	0.01	0.02	1.73
ALK	14	Normal	209	206	207	0.07
Turb.	45	Log-Normal	0.8	0.4	1.1	1.52
Hard.	39	Normal	240	240	240	0.08
DO	44	Normal	9.0	8.9	9.0	0.13
Cu	18	Log-Normal	0.5	0.13	1.2	1.67
Fe	18	Log-Normal	3	0.94	6	1.20
Pb	18	Log-Normal	0	0.12	1.3	1.39
Zn	18	Log-Normal	3.5	0.5	5.4	0.73
Fe. Col.	23	Log-Normal	76	64	98	0.86
Fe. Stp.	23	Log-Normal	72	88	245	0.92

* See Table 1 for units.

TABLE 22

BASEFLOW WATER QUALITY FOR BARTON CREEK @ LOOP 360*

Parameters	No. of Data Pts.	Distribution	Median	G.M.	A.M.	Coeff. of Variation
TSS	16	Log-Normal	1	1.2	3	1.61
TDS	12	Normal	237	240	242	0.10
BOD	16	Normal/Log-N.	0.45	0.37	0.47	0.60
TOC	17	Log-Normal	2.8	3.0	3.6	0.62
NO_3	13	Normal	0.08	0.05	0.10	0.95
$NO_2 + NO_3$	17	Normal	0.10	0.07	0.12	0.92
TKN	17	Log-Normal	0.26	0.20	0.33	0.81
TN	17	Log-Normal	0.35	0.35	0.45	0.65
NH_3	17	Log-Normal	0.01	0.01	0.02	1.24
TP	17	Log-Normal	0.01	0.01	0.02	2.10
ALK	6	Normal/Log-N.	185	187	187	0.11
Turb.	16	Log-Normal	0.65	0.40	0.73	0.82
Hard.	12	Normal-Log-N.	215	211	213	0.14
DO	16	Normal/Log-N.	8.9	9.1	9.2	0.13
Cu	12	Log-Normal	1	0.3	2.6	1.45
Fe	11	Log-Normal	10	4.0	7.4	0.52
Pb	12	Log-Normal	1	0.3	4.2	1.74
Zn	12	Log-Normal	3	3.8	4.3	0.62
Fe. Col.	17	Log-Normal	20	20	30	0.92
Fe. Stp.	17	Log-Normal	80	93	219	1.53

* See Table 1 for units.

TABLE 23

BASEFLOW WATER QUALITY FOR ONION CREEK @ HWY. 183*

Parameters	No. of Data Pts.	Distribution	Median	G.M.	A.M.	Coeff. of Variation
TSS	43	Log-Normal	5	6	7	0.76
TDS	42	Normal	328	327	330	0.15
BOD	43	Log-Normal	0.7	0.67	0.8	0.61
TOC	41	Log-Normal	3.4	3.61	410	0.51
NO_3	39	Log-Normal	0.38	0.21	0.59	1.79
$NO_2 + NO_3$	45	Log-Normal	0.39	0.23	0.60	1.83
TKN	44	Log-Normal	0.41	0.43	0.52	0.68
TN	44	Log-Normal	0.79	0.84	1.08	1.09
NH_3	45	Log-Normal	0.04	0.03	0.07	1.99
TP	45	Log-Normal	0.01	0.02	0.17	3.08
ALK	12	Normal	185	187	188	0.12
Turb.	42	Log-Normal	3.9	2.9	3.8	0.65
Hard.	42	Normal	225	224	225	0.13
DO	44	Normal	9.3	9	9.3	0.20
Cu	20	Log-Normal	1	0.2	0.7	0.94
Fe	20	Normal	10	2.3	8.4	0.79
Pb	20	Log-Normal	0	0.1	1.2	1.65
Zn	20	Log-Normal	4	1.7	6.5	1.04
Fe. Col.	43	Log-Normal	52	56	490	4.38
Fe. Stp.	43	Log-Normal	92	74	142	1.16

* See Table 1 for units.

TABLE 24

BASEFLOW WATER QUALITY FOR BEAR CREED NEAR DRIFTWOOD*

Parameters	No. of Data Pts.	Distribution	Median	G.M.	A.M.	Coeff. of Variation
TSS	20	Log-Normal	1	1	1.9	1.09
TDS	16	Normal	296	293	294	0.06
BOD	17	Log-Normal	0.4	0.33	0.53	0.82
TOC	17	Log-Normal	0.4	0.33	0.53	0.82
NO_3	16	Normal	0.12	0.11	0.20	0.71
$NO_2 + NO_3$	20	Normal	0.13	0.12	0.21	0.68
TKN	20	Log-Normal	0.33	0.27	0.37	0.75
TN	20	Normal	0.32	0.44	0.33	0.57
NH_3	20	Log-Normal	0.04	0.027	0.05	0.98
TP	20	Log-Normal	0.03	0.015	0.03	1.67
ALK	13	Normal/Log N.	230	224	223	0.07
Turb.	19	Normal	0.8	0.63	0.88	0.60
Hard.	16	Normal	270	265	265	0.07
DO	20	Normal	8.9	8.4	8.6	0.19
Cu	8	Log-Normal	1	0.32	0.75	0.62
Fe	8	Normal	5	5.0	5.6	0.52
Pb	8	Normal	1.5	0.56	2	1.00
Zn	8	Log-Normal	8	6.5	6	0.76
Fe. Col.	20	Log-Normal	81	71	115	1.05
Fe. Stp.	20	Log-Normal	65	85	207	1.54

* See Table 1 for units.

TABLE 25

BASEFLOW WATER QUALITY FOR BULL CREEK @ LOOP 360*

Parameters	No. of Data Pts.	Distribution	Median	G.M.	A.M.	Coeff. of Variation
TSS	21	Log-Normal	2	1.9	4.3	1.76
TDS	16	Log-Normal	359	372	378	0.20
BOD	21	Log-Normal	0.7	0.70	0.84	0.70
TOC	20	Log-Normal	2.8	3.3	3.9	0.61
NO_3	20	Log-Normal	0.09	.08	.11	1.99
$NO_2 + NO_3$	20	Log-Normal	.10	.10	.13	1.95
TKN	20	Log-Normal	0.3	.33	.04	0.74
TN	20	Log-Normal	0.46	.46	0.53	0.58
NH_3	20	Log-Normal	0.02	.016	0.03	1.03
TP	20	Log-Normal	0.01	.01	0.01	0.65
ALK	11	Normal	198	196	197	0.08
Turb.	20	Normal/Log-N.	1.8	1.5	1.9	0.71
Hard.	16	Normal/Log-N.	270	270	271	0.10
DO	20	Normal	8.5	8.3	8.6	0.27
Cu	11	Log-Normal	1.0	.6	2.2	1.71
Fe	11	Log-Normal	8	8	12	1.16
Pb	11	Log-Normal	1	.2	1.5	1.34
Zn	11	Log-Normal	3	4.6	5.7	0.91
Fe. Col.	21	Log-Normal	130	91	192	1.21
Fe. Stp.	21	Log-Normal	240	189	482	1.50

* See Table 1 for units.

TABLE 26

BASEWFLOW WATER QUALITY FOR SLAUGHTER CREEK AT FM 1826*

Parameters	No. of Data Pts.	Distribution	Median	G.M.	A.M.	Coeff. of Variation
TSS	11	Log-Normal	2	2	2.6	0.68
TDS	11	Normal	400	395	396	0.09
BOD	11	Log-Normal	0.5	0.41	0.83	1.00
TOC	11	Log-Normal	1.6	1.8	2.0	0.47
NO_3	11	Normal	0.19	0.19	0.21	0.65
$NO_2 + NO_3$	11	Normal	0.20	0.20	0.22	0.67
TKN	11	Log-Normal	0.30	0.39	0.27	0.48
TN	11	Normal	0.59	0.58	0.65	0.39
NH_3	11	Log-Normal	0.05	0.04	0.048	0.72
TP	11	Log-Normal	0.01	0.02	0.03	1.82
ALK	10	Normal	249	242	243	0.08
Turb.	11	Log-Normal	1	0.87	1.03	0.55
Hard.	9	Normal	320	324	324	0.09
DO	11	Normal	9.8	9.3	9.5	0.18
Cu	5	---	---		---	---
Fe	4	---	---		---	---
Pb	4	---	---		---	---
Zn	4	---	---		---	---
Fe. Col.	11	Log-Normal	25	23	75	1.20
Fe. Stp.	11	Log-Normal	68	52	378	2.19

* See Table 1 for units.

TABLE 27

BASEFLOW WATER QUALITY FOR WILLIAMSON CREEK @ OAK HILL*

Parameters	No. of Data Pts.	Distribution	Median	G.M.	A.M.	Coeff. of Variation
TSS	33	Log-Normal	2	1.2	2.2	1.00
TDS	30	Log-Normal	367	361	365	0.09
BOD	33	Normal	0.7	0.5	0.7	0.66
TOC	33	Log-Normal	3.8	3.2	5.0	0.84
NO_3	23	Log-Normal	0.13	0.12	0.21	0.89
$NO_2 + NO_3$	33	Log-Normal	0.14	0.28	0.23	0.85
TKN	33	Log-Normal	0.30	0.30	0.34	0.47
TN	33	Log-Normal	0.59	0.52	0.56	0.35
NH_3	33	Log-Normal	0.03	0.02	0.04	0.86
TP	33	Log-Normal	0.19	0.13	0.15	0.75
ALK	9	Normal	300	297	297	0.05
Turb.	33	Log-Normal	0.7	0.25	0.8	0.96
Hard.	31	Log-Normal	330	314	320	0.16
DO	33	Normal	11.7	11.2	11.4	0.20
Cu	15	Log-Normal	1.8	0.14	0.5	1.58
Fe	15	Log-Normal	7.6	3.8	10.	1.11
Pb	15	Log-Normal	1.9	0.2	1.0	2.28
Zn	15	Log-Normal	3	0.52	3.7	0.72
Fe. Col.	16	Log-Normal	120	114	202	1.19
Fe. Stp.	16	Log-Normal	120	187	589	1.60

* See Table 1 for units.

TABLE 28

BASEFLOW WATER QUALITY FOR WALNUT CREEK @ WEBBERVILLE ROAD*

Parameters	No. of Data Pts.	Distribution	Median	G.M.	A.M.	Coeff. of Variation
TSS	29	Log-Normal	4	2.6	5	0.92
TDS	20	Normal	357	340	344	0.13
BOD	30	Log-Normal	0.6	.59	0.71	0.95
TOC	30	Log-Normal	3.3	3.5	3.90	0.55
NO_3	25	Normal	0.68	.35	0.60	0.75
$NO_2 + NO_3$	25	Normal	0.68	0.35	0.60	0.75
TKN	30	Log-Normal	0.40	.39	0.44	0.55
TN	30	Normal	0.97	0.83	0.98	0.56
NH_3	30	Log-Normal	0.025	0.021	0.041	1.25
TP	30	Log-Normal	0.02	0.02	0.03	0.93
ALK	13	Normal/Log-N.	170	164	168	0.22
Turb.	28	Log-Normal	1.1	1.1	1.61	0.92
Hard.	20	Normal	255	233	241	0.23
DO	30	Normal/Log-N.	8.7	9.0	9.3	0.23
Cu	11	Log-Normal	1	0.6	1.6	1.10
Fe	12	Log-Normal	4.5	2.5	8.3	0.94
Pb	11	Log-Normal	1	.2	1	1.48
Zn	12	Log-Normal	3	2.4	4.1	0.68
Fe. Col.	30	Log-Normal	240	265	640	2.01
Fe. Stp.	30	Log-Normal	250	299	571	1.28

* See Table 1 for units.

TABLE 29

BASEFLOW WATER QUALITY FOR BOGGY CREEK @ HWY. 183*

Parameters	No. of Data Pts.	Distribution	Median	G.M.	A.M.	Coeff. of Variation
TSS	32	Log-Normal	3.5	3.1	8.0	2.20
TDS	21	Normal/Log-N.	383	380	380	0.14
BOD	32	Log-Normal	0.6	0.52	0.8	1.14
TOC	32	Log-Normal	3.8	3.6	5.0	0.84
NO_3	25	Normal	0.58	0.24	0.52	0.77
$NO_2 + NO_3$	32	Normal	0.60	0.27	0.54	0.79
TKN	31	Normal/Log-N.	0.25	0.27	0.35	0.64
TN	31	Normal/Log-N.	0.79	0.67	0.79	0.52
NH_3	32	Log-Normal	0.02	0.014	0.03	1.12
TP	32	Log-Normal	0.03	0.03	0.05	1.03
ALK	9	Normal-Log-N.	194	192	197	0.10
Turb.	32	Log-Normal	1.6	1.3	3.1	1.41
Hard.	21	Normal	250	247	258	0.24
DO	32	Normal/Log-N.	10.8	11.	11.4	0.25
Cu	15	Log-Normal	1	0.3	1.7	1.58
Fe	15	Log-Normal	10	0.5	8.7	1.11
Pb	15	Log-Normal	0	0.1	1.1	2.28
Zn	15	Log-Normal	10	4.7	8.3	0.72
Fe. Col.	32	Log-Normal	390	450	1267	1.44
Fe. Stp.	32	Log-Normal	450	391	978	1.83

* See Table 1 for units.

TABLE 30

BASEFLOW WATER QUALTIY FOR SHOAL CREEK @ 12TH STREET*

Parameters	No. of Data Pts.	Distribution	Median	G.M.	A.M.	Coeff. of Variation
TSS	17	Log-Normal	3	3	7	1.21
TDS	9	Normal	390	395	400	0.16
BOD	18	Normal/Log-N.	0.8	.63	0.8	0.54
TOC	18	Normal/Log-N.	3.6	3.5	3.6	0.28
NO_3	11	Log-Normal	0.46	.32	0.57	1.17
$NO_2 + NO_3$	18	Log-Normal	0.41	.39	0.40	1.21
TKN	18	Log-Normal	0.37	.41	0.54	1.06
TN	18	Log-Normal	0.77	.80	1.08	1.05
NH_3	18	Log-Normal	0.03	.02	0.05	0.93
TP	18	Log-Normal	0.03	.03	0.05	1.21
ALK	5	Normal	1465	1545	146	0.12
Turb.	18	Log-Normal	1.	.9	2.2	1.23
Hard.	9	Normal	270	270	274	0.18
DO	18	Normal	9.9	9.4	9.7	0.25
Cu	7	Normal	2.0	.5	1.9	0.95
Fe	7	Log-Normal	10	4.5	18	1.20
Pb	7	Log-Normal	1	.18	1.1	1.55
Zn	7	Log-Normal	13		10	0.61
Fe. Col.	18	Log-Normal	2450	2732	7404	1.62
Fe. Stp.	18	Log-Normal	1250	1319	2111	1.01

* See Table 1 for units.

TABLE 31

BASEFLOW WATER QUALTIY FOR WALNUT CREEK @ SOUTHERN PACIFIC RAILROAD BRIDGE*

Parameters	No. of Data Pts.	Distribution	Median	G.M.	A.M.	Coeff. of Variation
TSS	37	Log-Normal	9	10.	14	0.88
TDS	26	Normal	387	407	408	0.08
BOD	38	Log-Normal	8.3	7.1	9.8	0.78
TOC	38	Log-Normal	9.8	9.3	10.3	0.36
NO_3	38	Normal	4.9	3.1	5.0	0.81
$NO_2 + NO_3$	38	Normal	5.1	3.5	5.3	0.83
TKN	38	Log-Normal	4.5	4.0	5.5	0.83
TN	38	Normal	11.7	9.8	11.2	0.49
NH_3	38	Log-Normal	1.6	0.93	2.4	1.26
TP	38	Log-Normal	5.2	3.4	4.9	0.56
ALK	11	Normal	110	110	110	0.14
Turb.	37	Log-Normal	4.9	4.8	6.1	0.92
Hard.	26	Normal	180	185	189	0.20
DO	38	Normal	6.8	6.8	7.3	0.35
Cu	18	Log-Normal	3.0	3.0	7.6	1.55
Fe	18	Log-Normal	31.5	12	37.2	1.31
Pb	18	Log-Normal	0.5	0.13	0.9	1.23
Zn	18	Normal	20	12	19	0.61
Fe. Col.	38	Log-Normal	78	18	20392	5.96
Fe. Stp.	38	Log-Normal	80	45	816	4.35

* See Table 1 for units.

TABLE 32

BASEFLOW WATER QUALITY FOR BARTON SPRINGS*

Parameters	No. of Data Pts.	Distribution	Median	G.M.	A.M.	Coeff. of Variation
TSS	66	Log-Normal	2	2	5.6	2.27
TDS	20	Log-Normal	328	337	340	0.11
BOD	21	Log-Normal	0.30	0.28	0.40	1.00
TOC	65	Log-Normal	0.60	0.58	1.57	2.34
NO_3	59	Log-Normal	1.40	1.12	1.29	0.24
$NO_2 + NO_3$	67	Log-Normal	1.41	1.15	1.33	0.25
TKN	66	Log-Normal	0.50	0.47	0.58	0.73
TN	66	Log-Normal	1.86	1.83	1.90	0.27
NH_3	67	Log-Normal	0.06	0.05	0.06	0.74
TP	67	Log-Normal	0.01	0.02	0.02	1.43
ALK	16	Log-Normal	252	251	252	0.09
Turb.	23	Log-Normal	0.7	0.8	0.86	0.53
Hard.	20	Log-Normal	292	287	288	0.08
DO	67	Normal	6.4	6.5	6.6	0.17
Cu	10	Log-Normal	1	0.4	2.5	1.59
Fe	10	Log-Normal	3	3	13.2	1.98
Pb	10	Log-Normal	1.5	0.6	3.3	1.19
Zn	10	Log-Normal	3.5	4.6	5.2	0.53
Fe. Col.	71	Log-Normal	10	15	142	4.02
Fe. Stp.	71	Log-Normal	9	14	78	2.58

* See Table 1 for units.

TABLE 33

BASEFLOW WATER QUALITY FOR WILLIAMSON CREEK @ JIMMY CLAY ROAD*

Parameters	No. of Data Pts.	Distribution	Median	G.M.	A.M.	Coeff. of Variation
TSS	39	Log-Normal	5	4.1	6.4	0.91
TDS	27	Normal	40	416	419	0.15
BOD	40	Log-Normal	1.5	1.4	2.0	0.97
TOC	40	Log-Normal	4.4	44	4.8	0.43
NO_3	39	Log-Normal	0.59	0.93	0.88	1.58
$NO_2 + NO_3$	40	Log-Normal	0.74	0.97	1.19	1.63
TKN	40	Log-Normal	0.88	0.99	1.39	1.23
TN	40	Log-Normal	1.72	2.29	3.38	1.27
NH_3	40	Log-Normal	0.33	0./28	0.66	1.53
TP	40	Log-Normal	0.05	0.06	0.67	2.94
ALK	14	Normal	233	220	230	0.28
Turb.	38	Log-Normal	2.8	2.4	3.4	0.97
Hard.	27	Normal	290	282	286	0.17
DO	40	Normal	7.2	7.0	7.3	0.29
Cu	20	Normal	1	0.24	1	1.08
Fe	20	Log-Normal	10	5.0	22	1.66
Pb	20	Log-Normal	0.5	0.2	1.1	1.47
Zn	20	Log-Normal	7	2.7	16.7	1.43
Fe. Col.	36	Log-Normal	250	266	1604	4.33
Fe. Stp.	36	Log-Normal	570	410	970	1.55

* See Table 1 for units.

TABLE 34

COMPARISONS OF BASEFLOW WATER QUALITY AMONG CREEKS
(VALUES ARE MEDIAN BASEFLOW CONCENTRATIONS)

Constituent Parameters	Onion Nr. Drift-wood 3*	Barton @ Loop 360 7	Bear Nr. Drift-wood 9	Bull @ Loop 360 12	Slaughter @ FM 1826 13	Williamson @ Oak Hill 15	Walnut @ Webberville Rd. 22	Boggy @ Hwy. 183 41	Shoal @ 12th St. 47
TSS**	1	1	1	2	2	2	4	4	3
TDS	270	237	296	359	400	267	357	383	390
BOD	0.5	0.45	0.4	0.6	0.5	0.7	0.6	0.6	0.8
TOC	1.7	2.8	1.9	2.8	1.6	3.8	3.3	3.8	3.6
NO_3	0.09	0.08	0.12	0.09	0.19	0.13	0.42	0.58	0.46
NO_2+NO_3	0.10	0.10	0.13	0.10	0.20	0.14	0.44	0.60	0.47
TKN	0.19	0.26	0.33	0.30	0.30	0.30	0.40	0.25	0.37
TN	0.33	0.35	0.60	0.46	0.59	0.59	0.97	0.97	0.77
NH_3	0.01	0.01	0.04	0.02	0.04	0.03	0.03	0.02	0.03
TP	0.01	0.01	0.01	0.01	0.01	0.02	0.03	0.03	0.03
ALK.	209	185	230	198	249	300	170	194	146
TURB.	0.8	0.65	0.8	1.8	1	0.7	1.1	1.6	1
HARD.	240	215	270	270	320	330	255	250	270
DO	9.0	8.9	8 .9	8.5	9.8	11.7	8.7	10.8	9.9
Cu	0.5	1	1	1	---	1.8	1	1	2
Fe	3	10	5	8	---	8	5	10	10
Pb	0	1	1.5	1	---	2	1	0	1
Zn	3.5	3	8	3	---	3	3	10	13
Fe. Col.	76	20	81	130	25	120	240	390	2450
Fe. Stp.	72	80	65	240	68	120	250	450	1250

* Percent imperviousness

** See Table 1 for units.

TABLE 35

WATER QUALITY DATA TREND ANALYSIS FOR AUSTIN CREEKS
(UNDER BASEFLOW CONDITION)

Creek	Period of Data	TSS	TDS	BOD	TOC	NO3	TKN	TN	NH3	TP	Cu	Pb	Zn
		Pollutant Parameters											
Onion Nr. Driftwood	75-87	NS*	NS	NS	NS	NS	HS	HS	NS	NS	NS	NS	NS
Barton @ Loop 360	78-87	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Onion @ Hwy. 183	75-87	NS	NS	NS	NS	NS	NS	NS	NS	HS	NS	NS	NS
Bear Nr. Driftwood	78-87	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Bull @ Loop 360	78-87	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Slaughter @ FM 1826	78-87	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Williamson @ Oak Hill	76-87	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Walnut @ Webberville	75-87	NS	NS	NS	NS	NS	HS	NS	HS	NS	NS	NS	NS
Boggy @ Hwy. 183	75-87	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Shoal @ 12th St.	75-87	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Walnut @ So. Pac. Rail Rd. Bridge	76-87	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Williamson @ Jimmy Clay Rd.	75-87	NS	NS	NS	NS	HS	NS	HS	NS	HS	NS	NS	NS
Barton Springs	75-87	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

* Data used are pollutant concentrations. NS indicates that the time trend is non-significant. HS indicates that the time trend is highly significant.

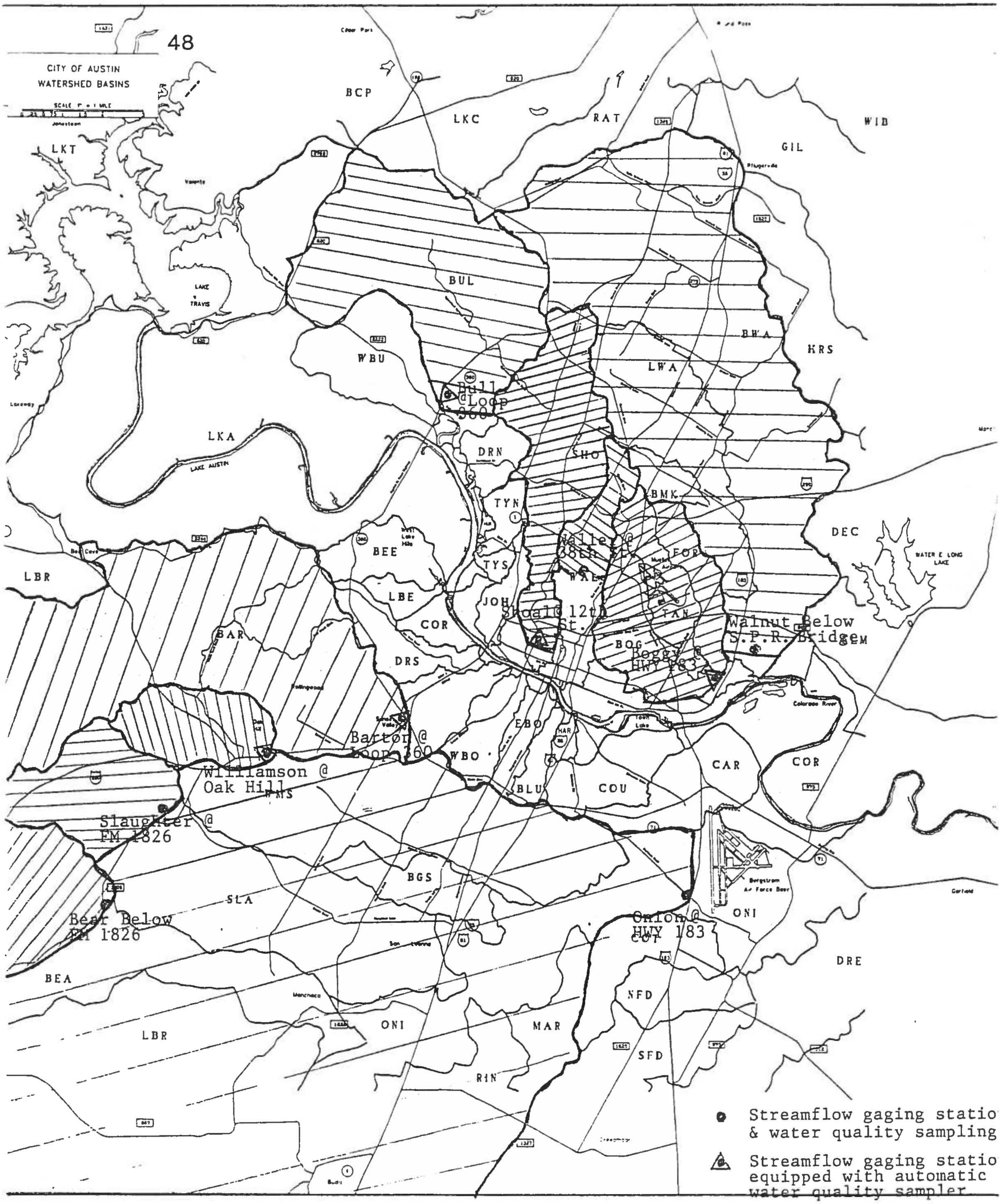

FIGURE 1. WATERSHED AND GAGING STATION LOCATION MAP

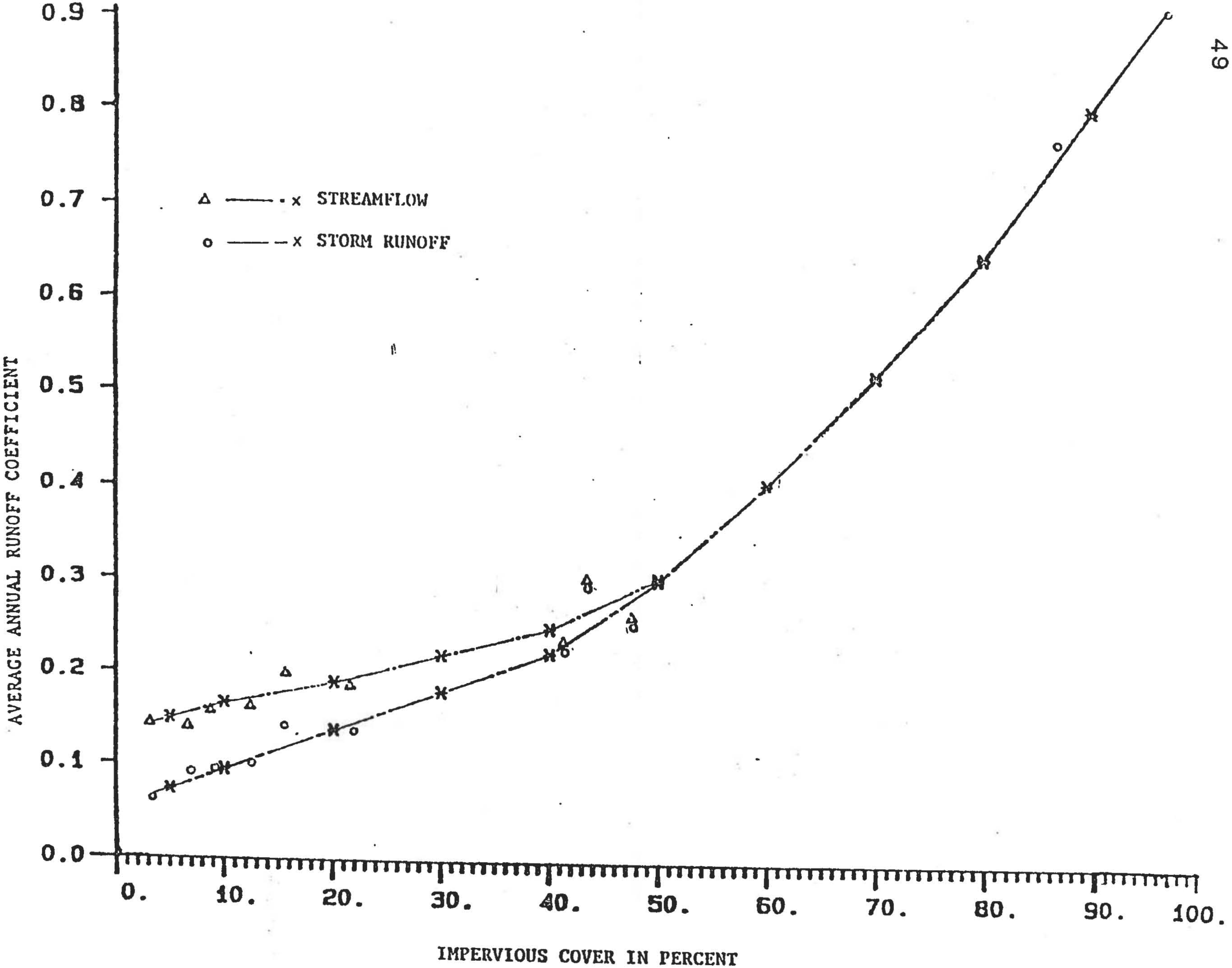

FIGURE 2. AVERAGE ANNUAL RUNOFF COEFFICIENTS VERSUS WATERSHED IMPERVIOUSNESS

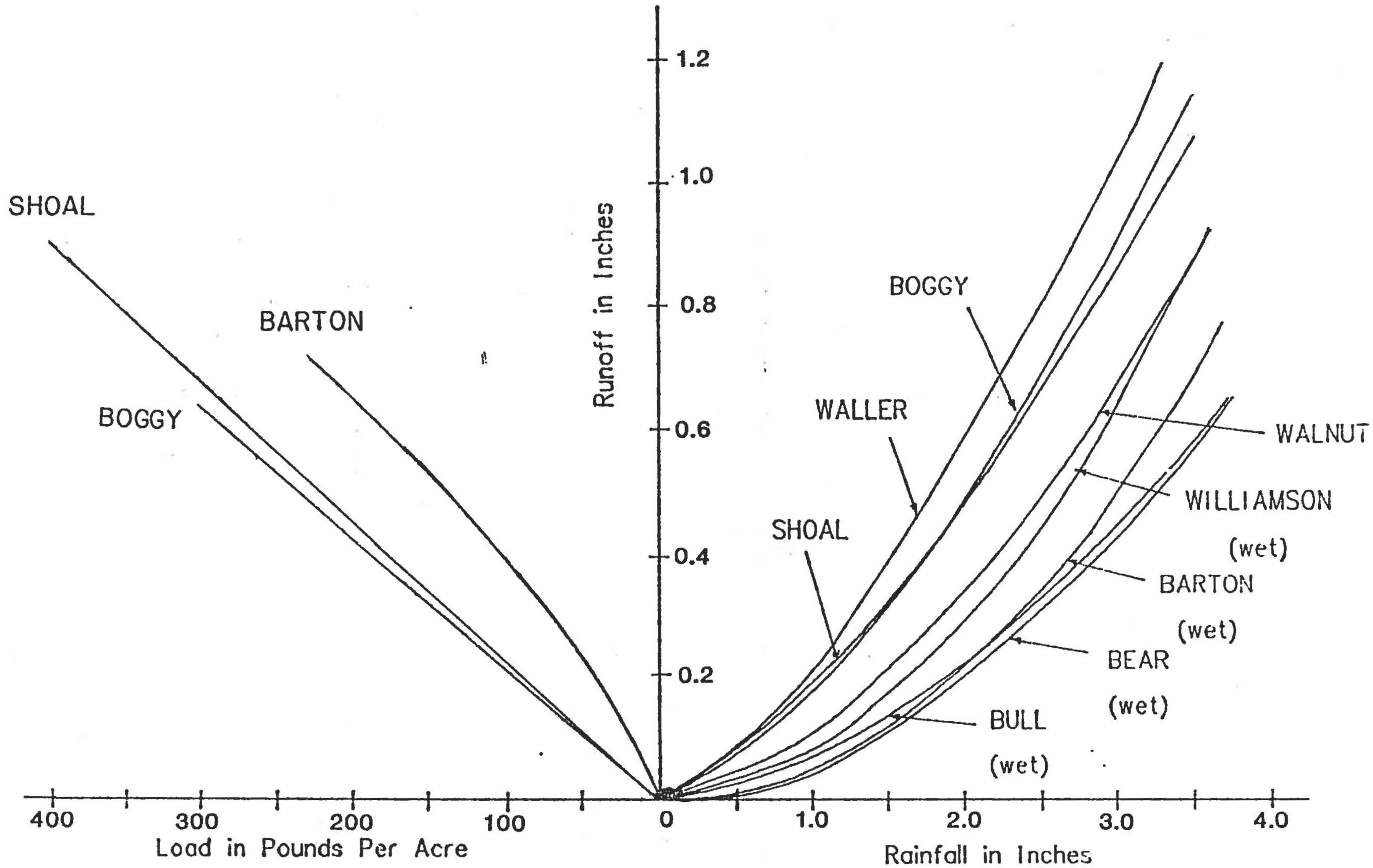

Figure 3. Storm Load – Runoff – Rainfall – Relationship For TSS

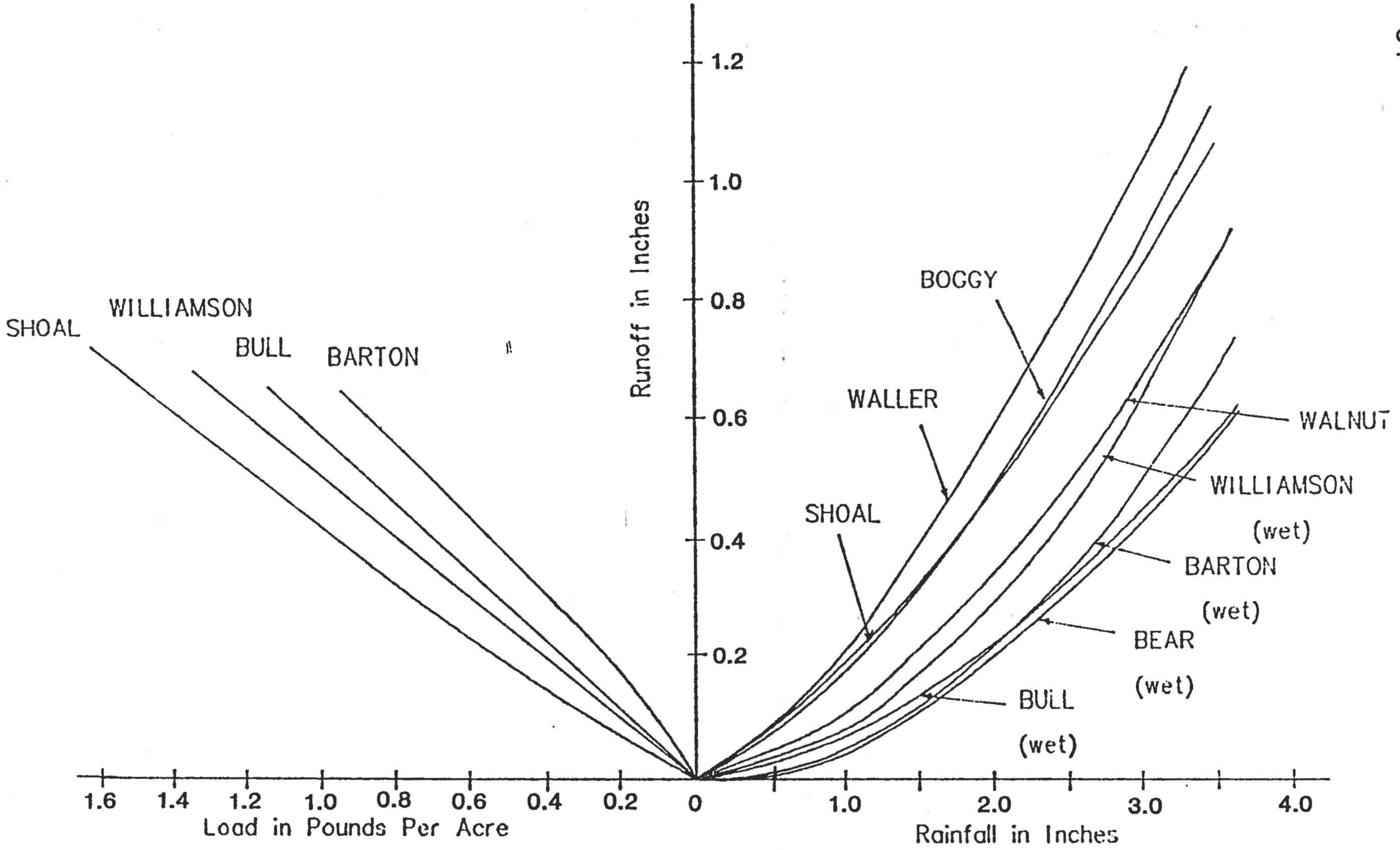

Figure 4. Storm Load – Runoff – Rainfall – Relationship For BOD

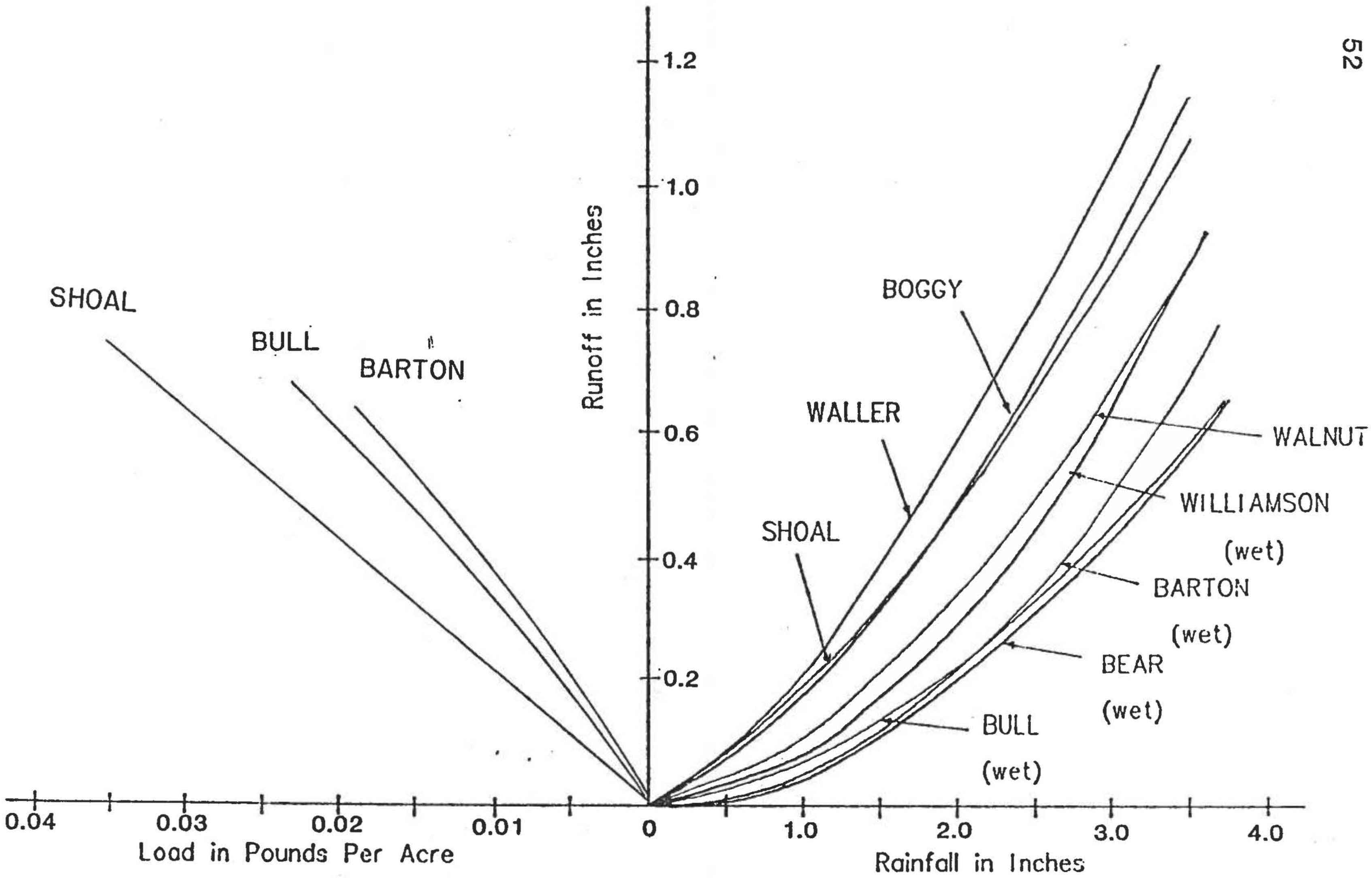

Figure 5. Storm Load – Runoff – Rainfall – Relationship For NH_3

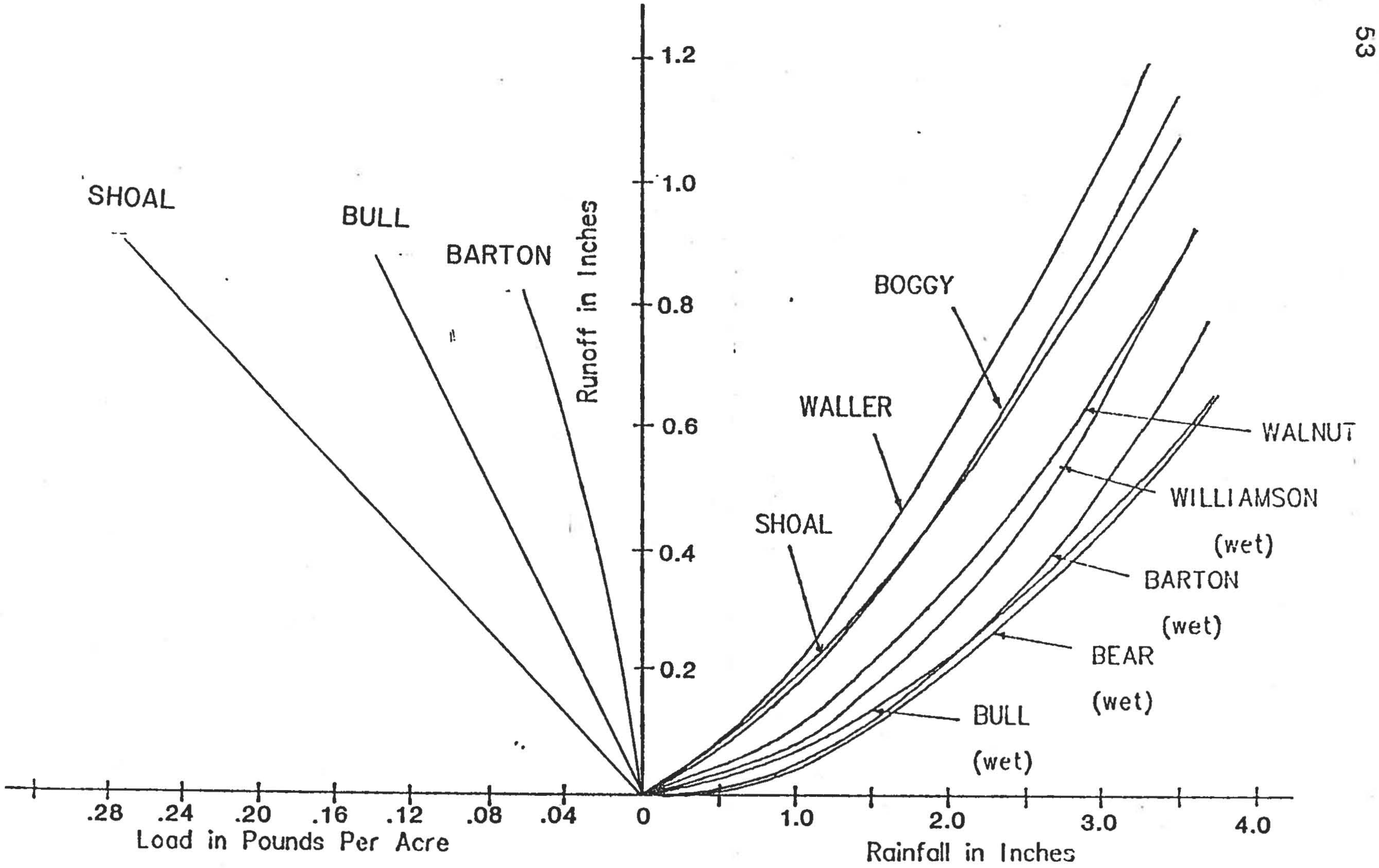

Figure 6. Storm Load – Runoff – Rainfall – Relationship For TP

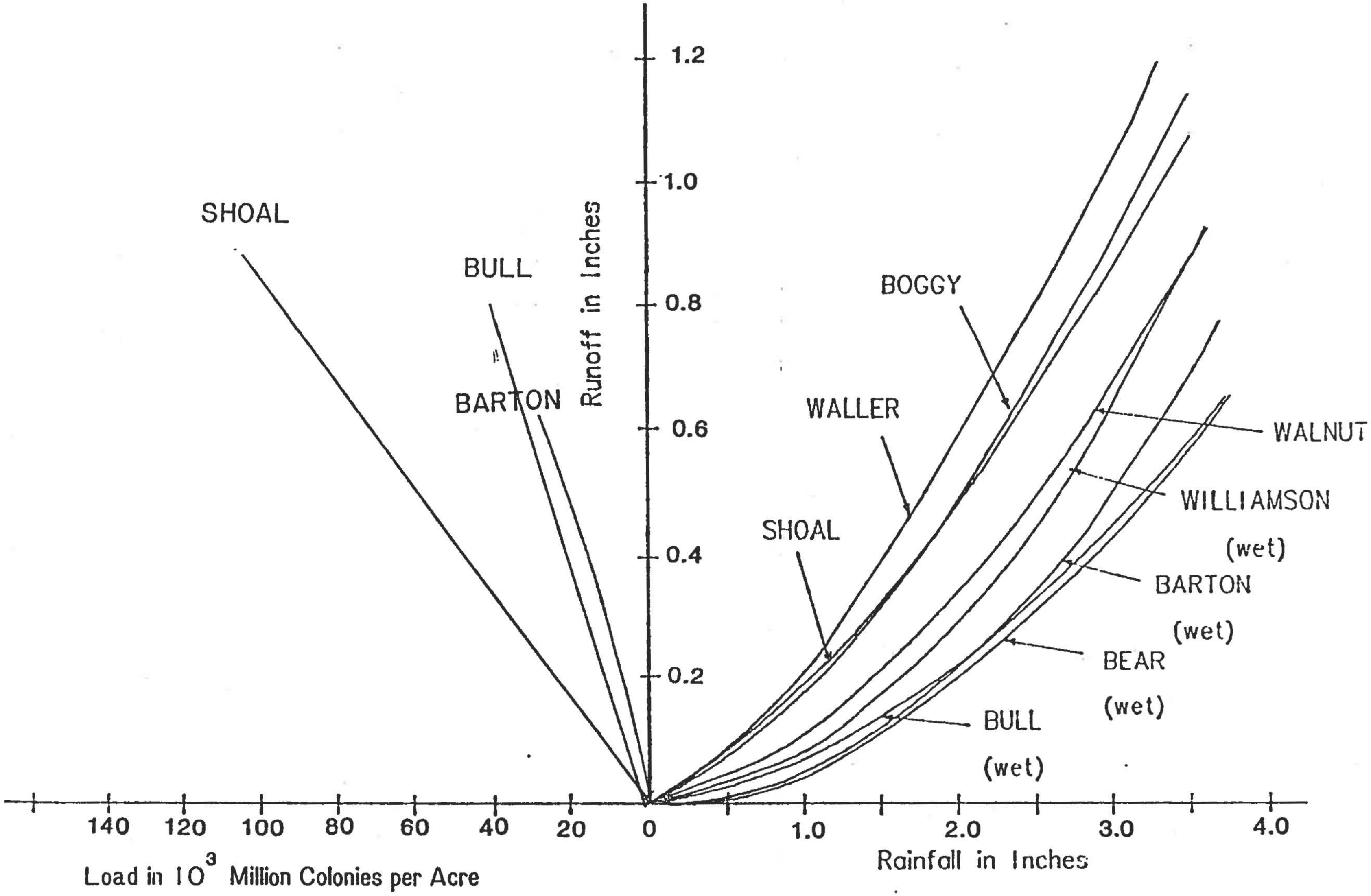

Figure 7. Storm Load – Runoff – Rainfall – Relationship For Fecal Coliform

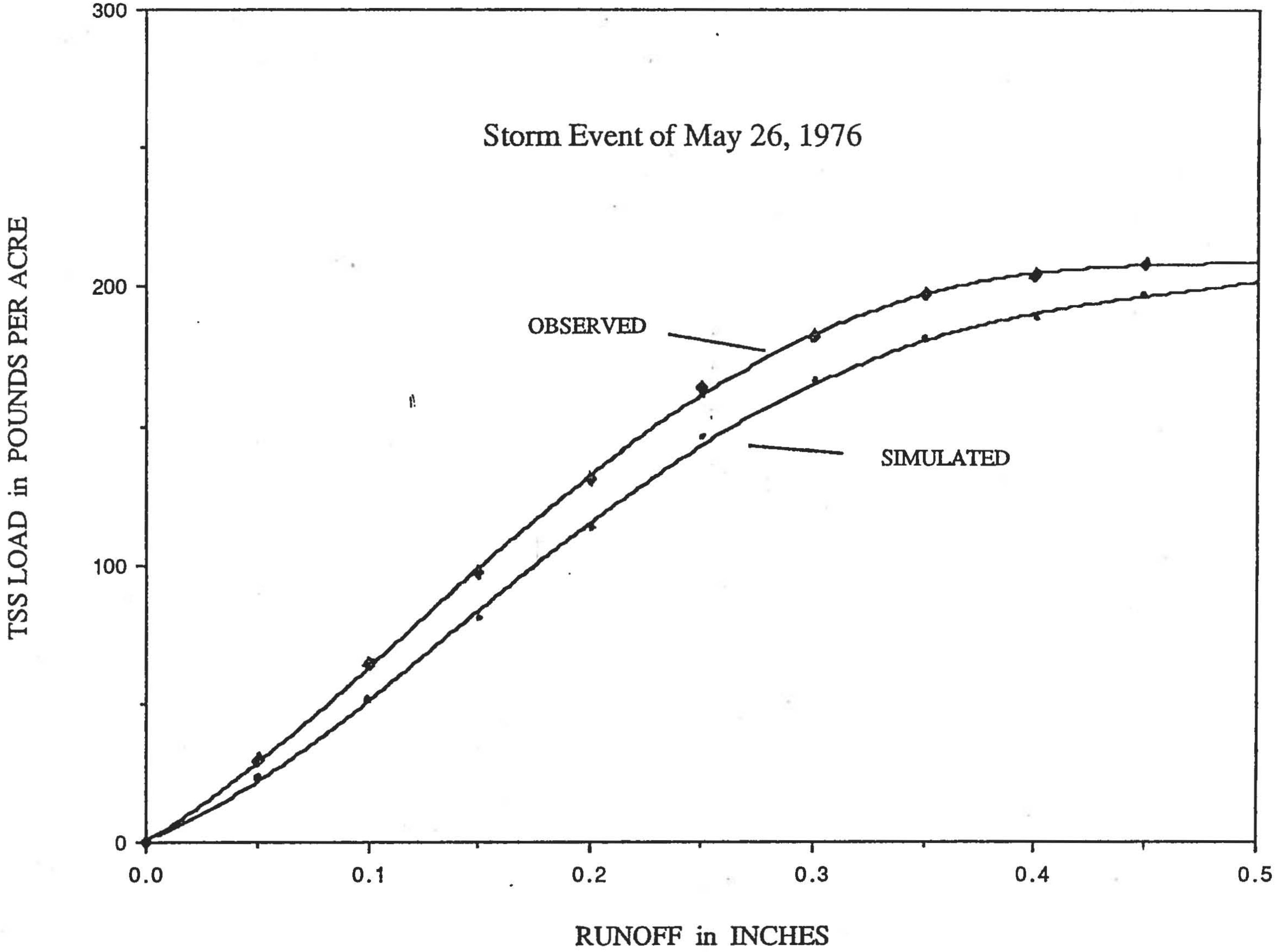

FIGURE 8. COMPARISON OF OBSERVED AND SIMULATED TSS LOAD-RUNOFF RELATIONSHIP FOR SHOAL CREEK

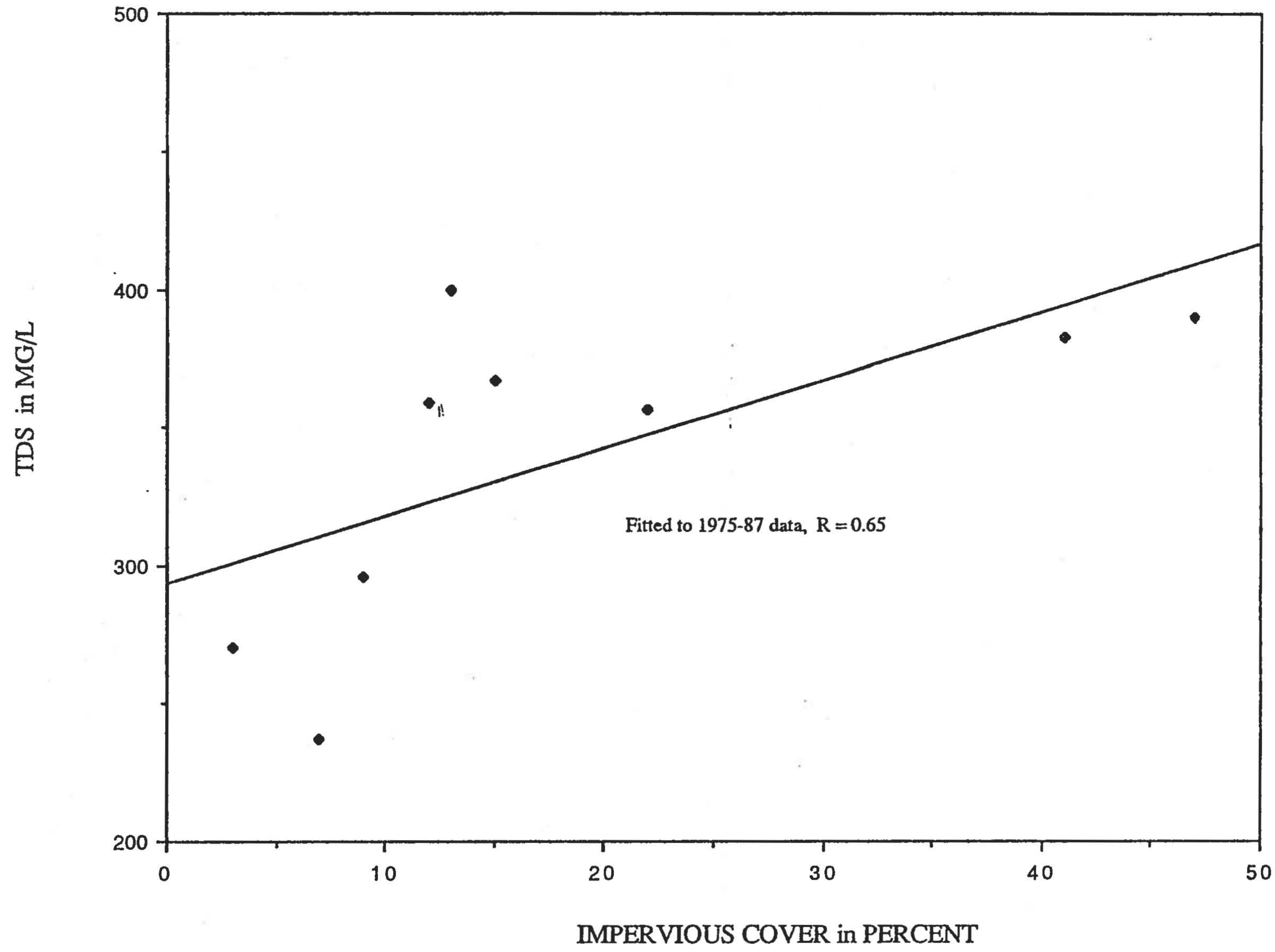

FIGURE 9. BASEFLOW WATER QUALITY CONDITIONS OF AUSTIN CREEKS
IN TERMS OF WATERSHED IMPERVIOUSNESS

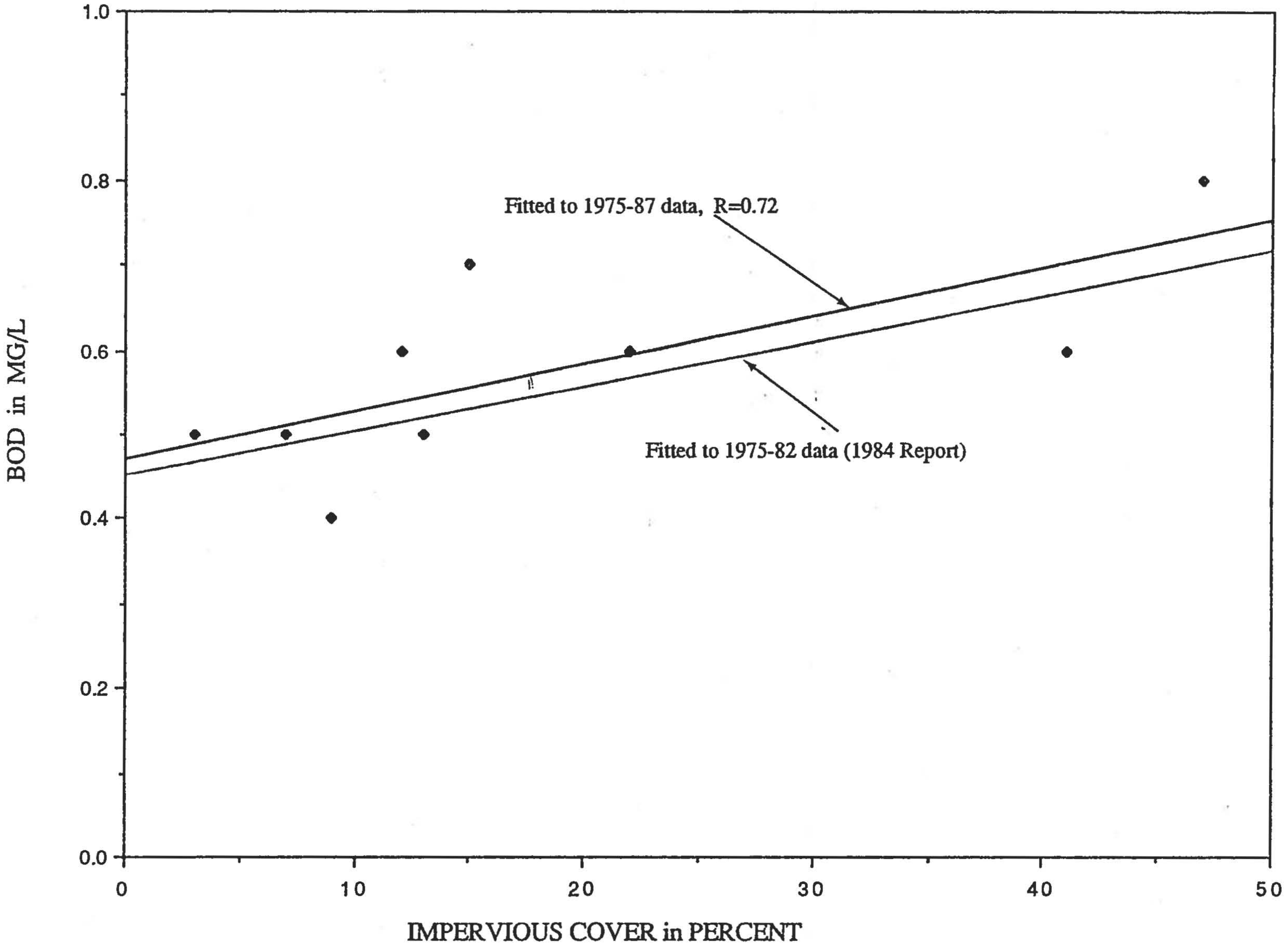

FIGURE 10. BASEFLOW WATER QUALITY CONDITIONS OF AUSTIN CREEKS INTERMS OF WATERSHED IMPERVIOUSNESS

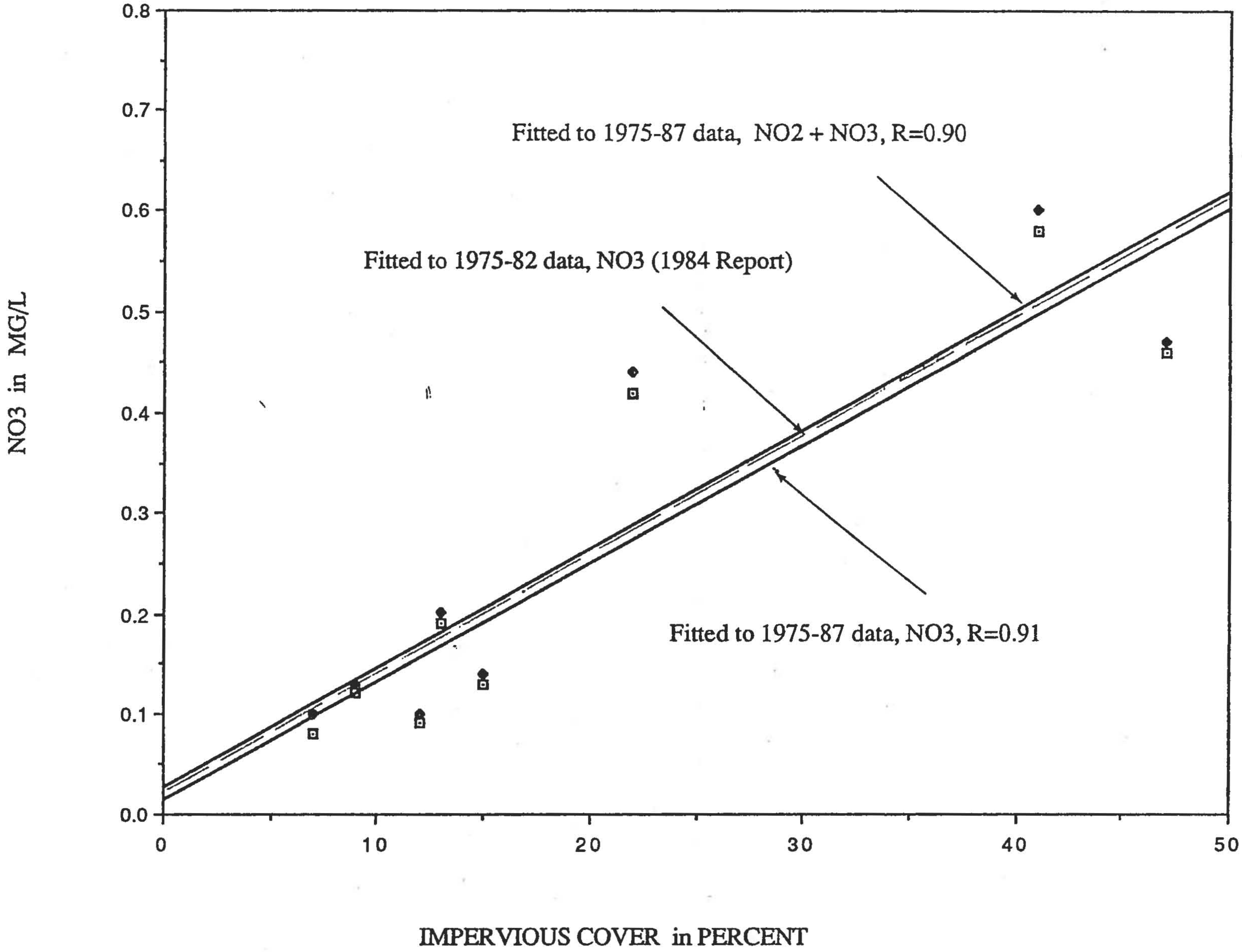

FIGURE 11. BASEFLOW WATER QUALITY CONDITIONS OF AUSTIN CREEKS IN TERMS OF WATERSHED IMPERVIOUSNESS

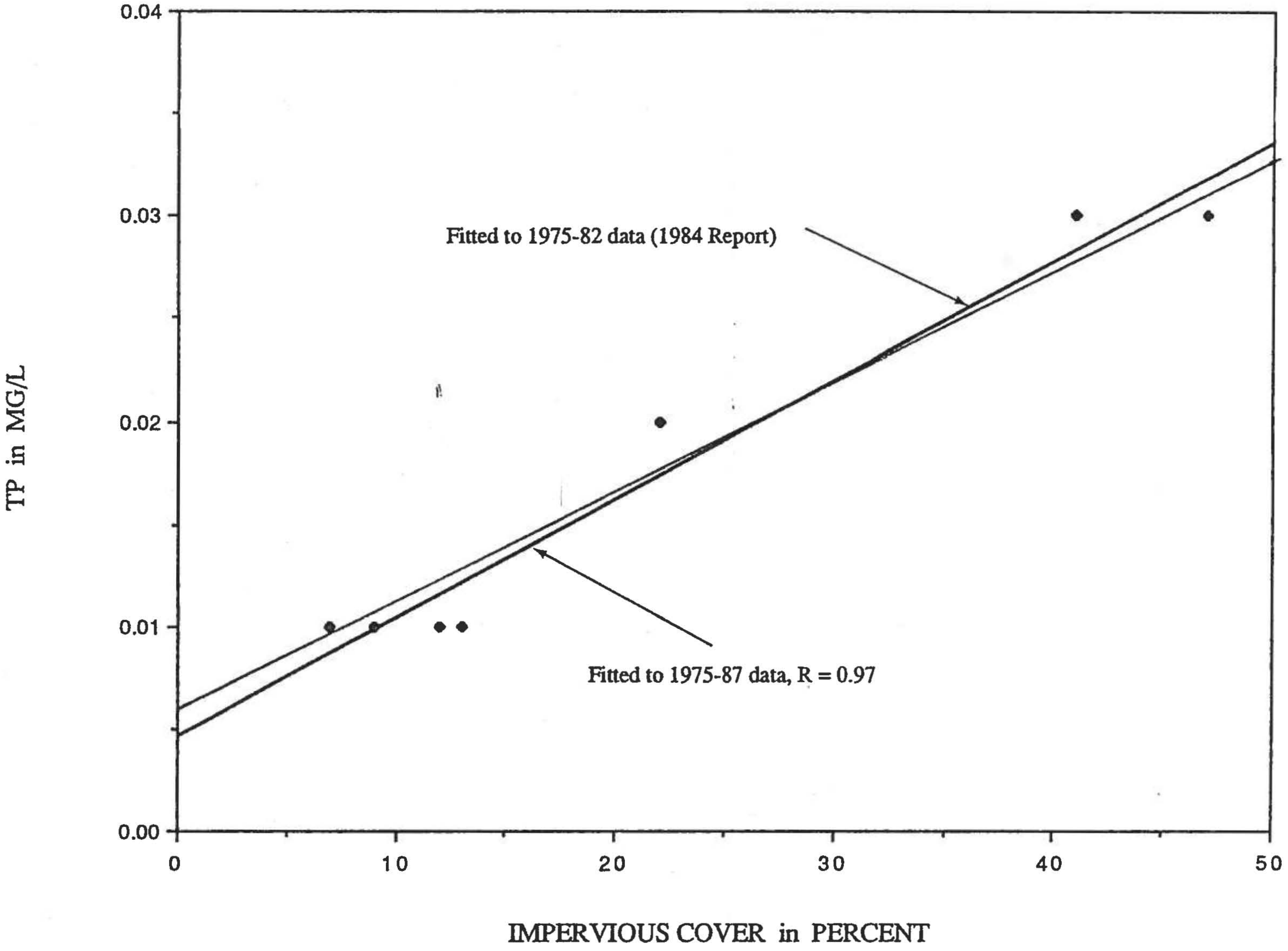

FIGURE 12. BASEFLOW WATER QUALITY CONDITIONS OF AUSTIN CREEKS IN TERMS OF WATERSHED IMPERVIOUSNESS

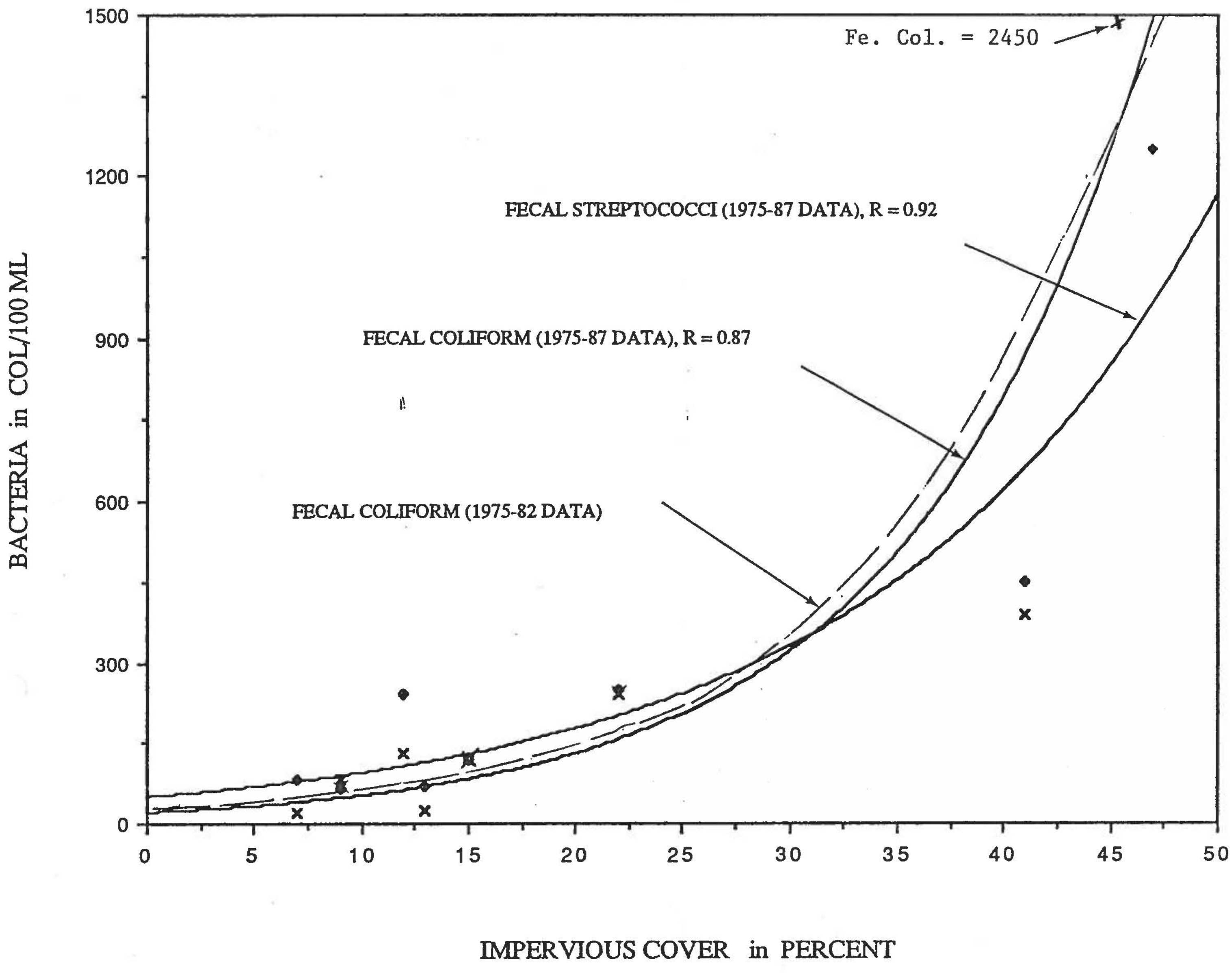

FIGURE 13. BASEFLOW WATER QUALITY CONDITIONS OF AUSTIN CREEKS IN TERMS OF WATERSHED IMPERVIOUSNESS

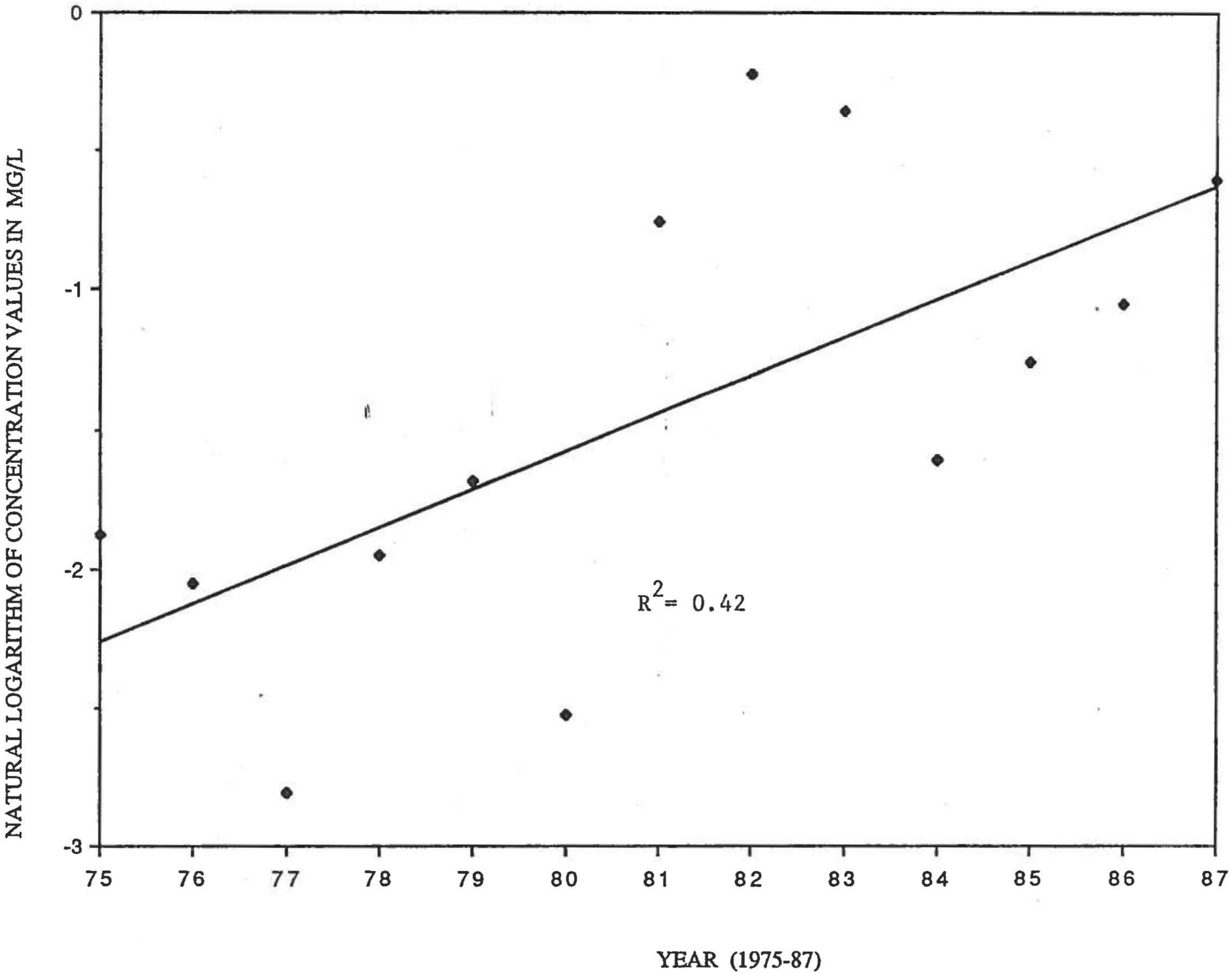

FIGURE 14. TREND ANALYSIS FOR TKN CONCENTRATION DATA
OF ONION CREEK NEAR DRIFTWOOD

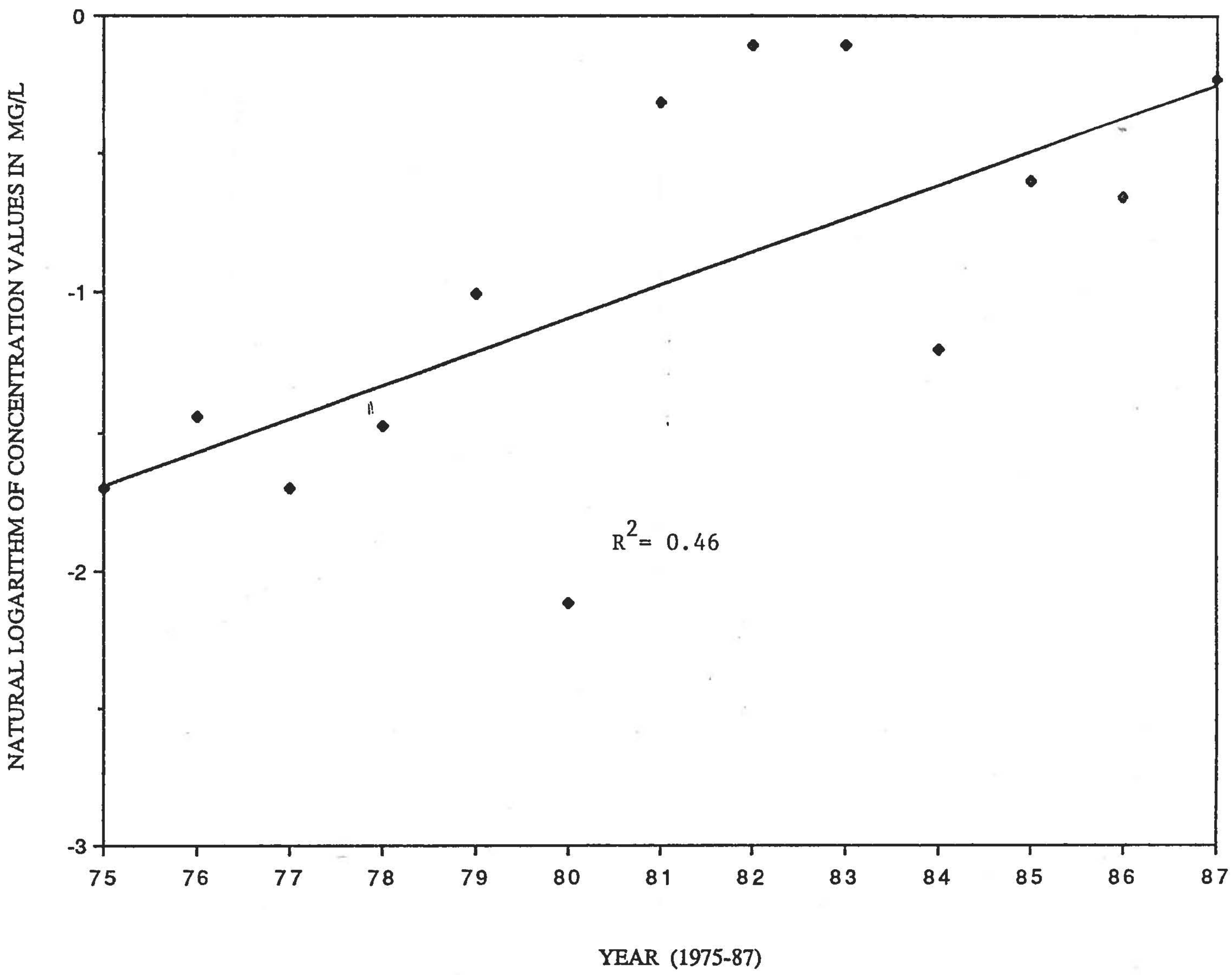

FIGURE 15. TREND ANALYSIS FOR TN CONCENTRATION DATA
OF ONION CREEK NEAR DRIFTWOOD

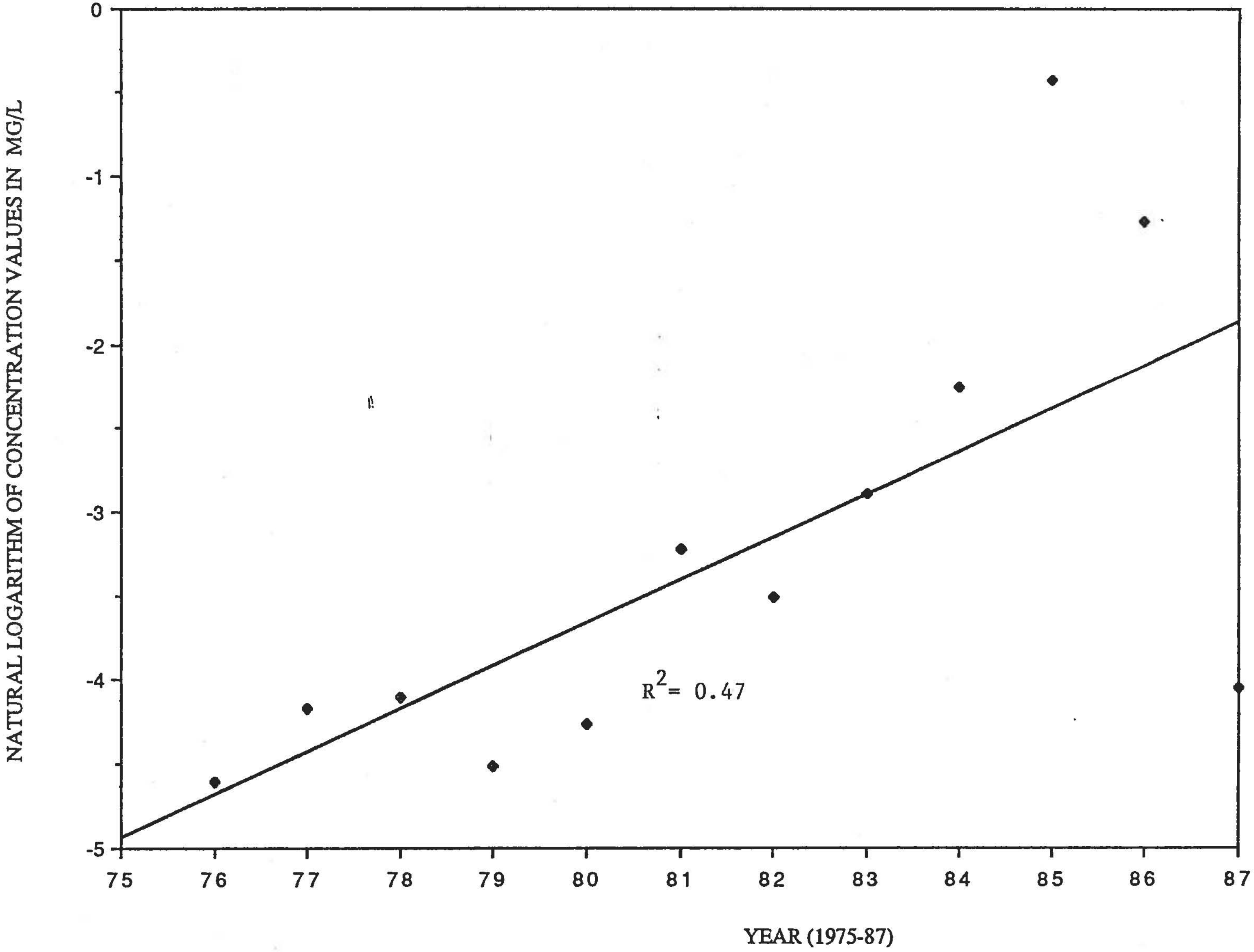

FIGURE 16. TREND ANALYSIS FOR TP CONCENTRATION DATA
OF ONION CREEK @ HWY 183

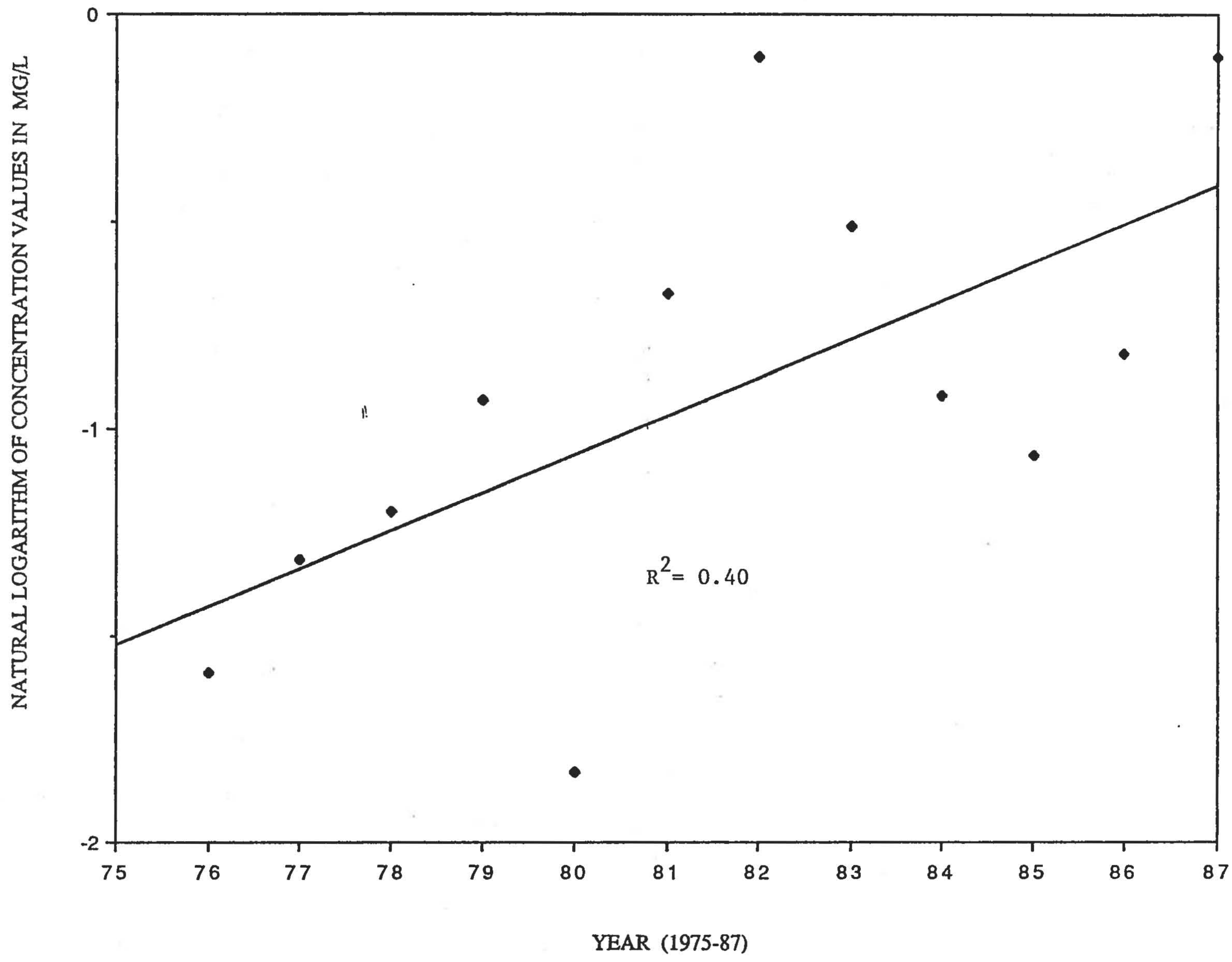

FIGURE 17. TREND ANALYSIS FOR TKN CONCENTRATION DATA
OF WALNUT CREEK @ WEBBERVILLE ROAD

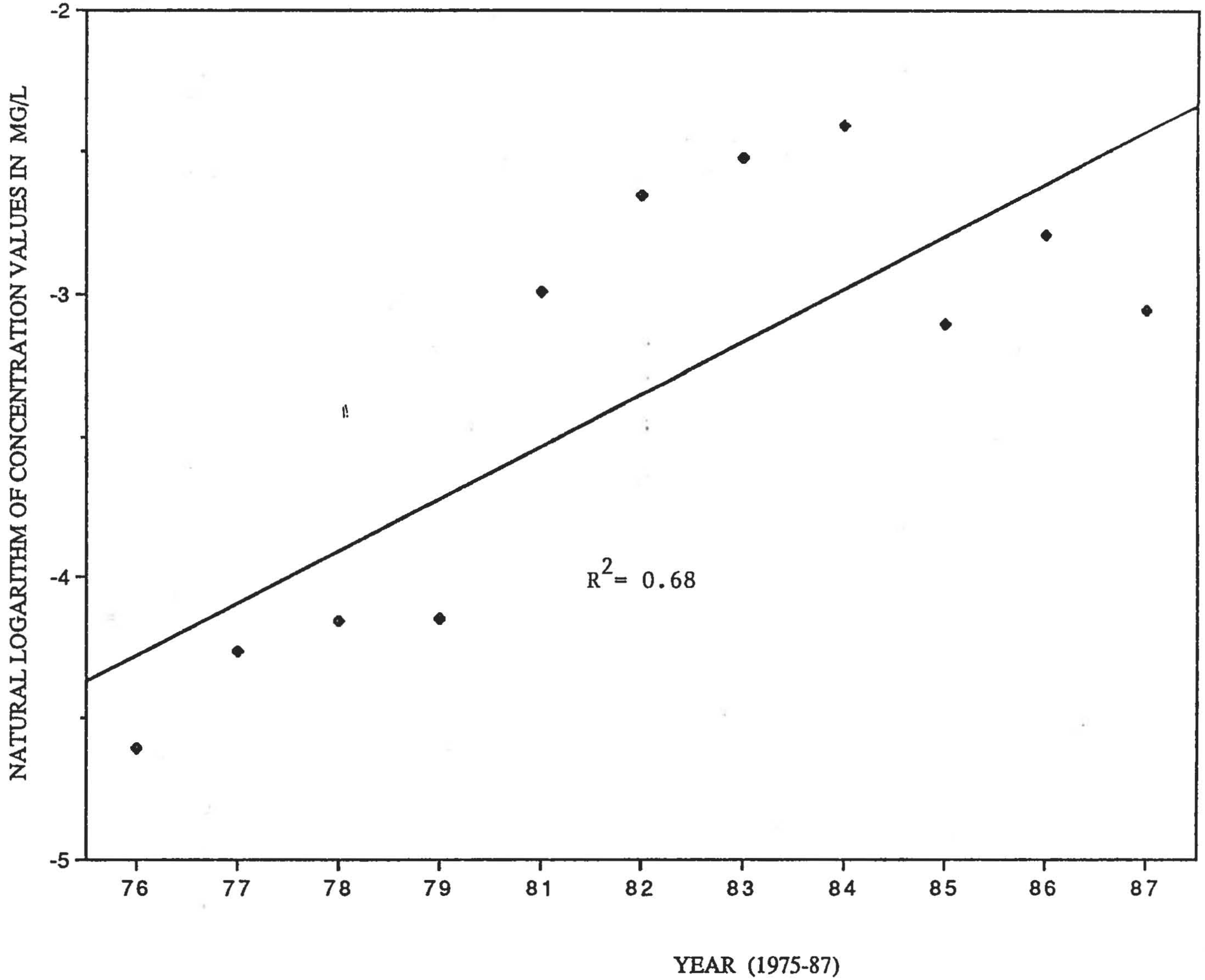

FIGURE 18. TREND ANALYSIS FOR NH3 CONCENTRATION DATA OF WALNUT CREEK @ WEBBERVILLE ROAD

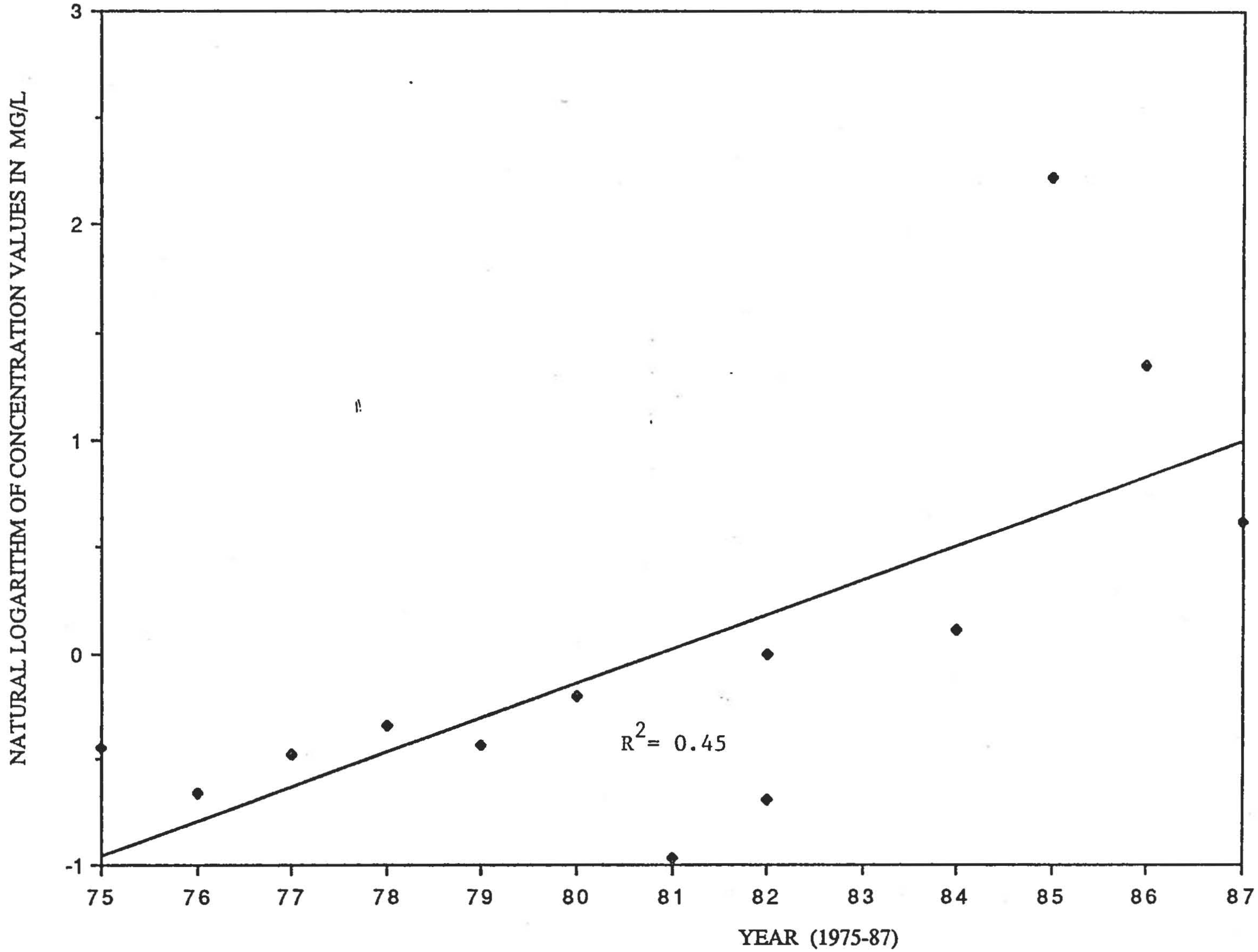

FIGURE 19. TREND ANALYSIS FOR NO3 CONCENTRATION DATA
OF WILLIAMSON CREEK @JIMMY CLAY ROAD

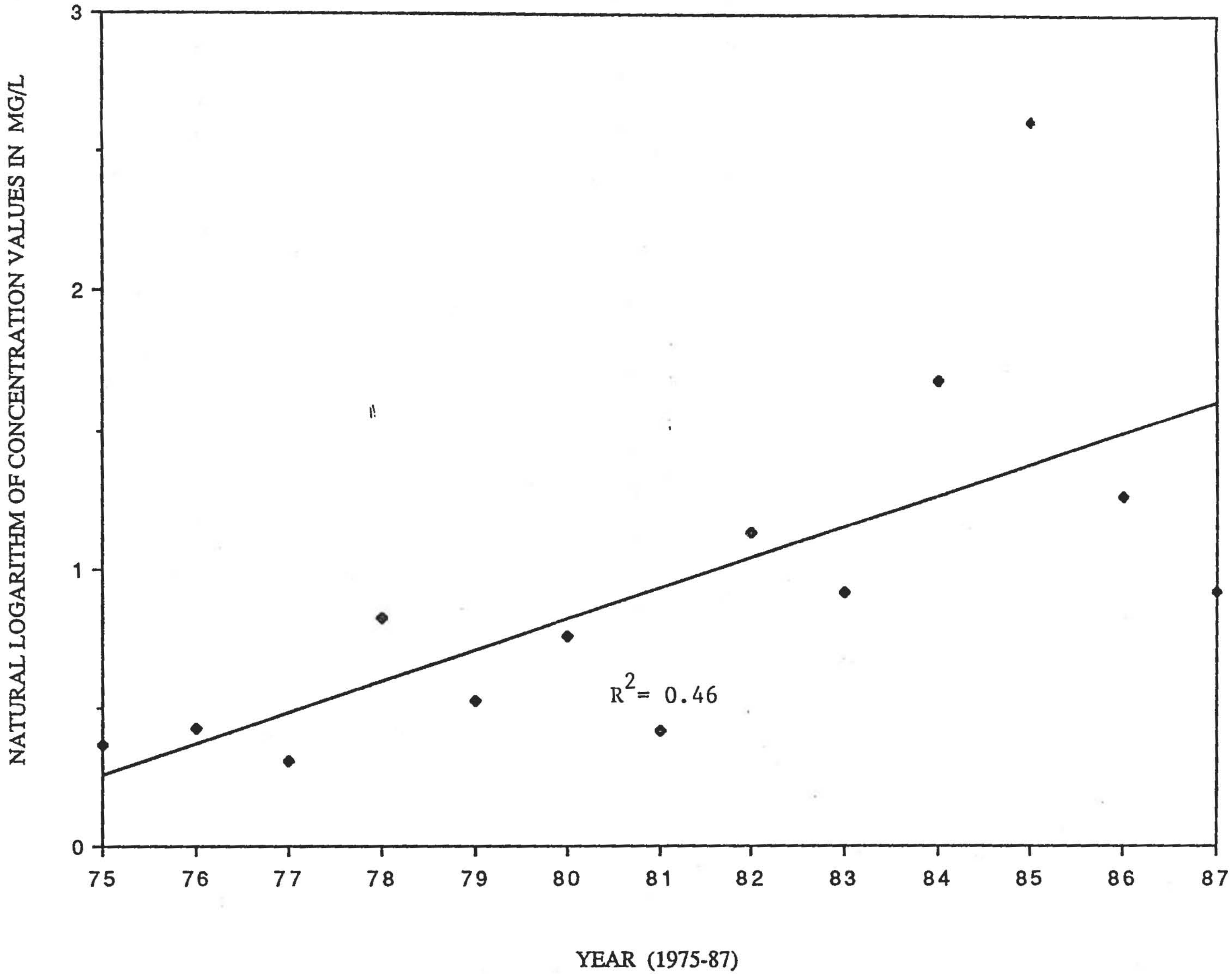

FIGURE 20. TREND ANALYSIS FOR TN CONCENTRATION DATA OF WILLIAMSON CREEK @ JIMMY CLAY ROAD